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INSTRUCTION REPORT K-81-7

USER'S GUIDE: COMPUTER PROGRAM FOR DESIGN OR INVESTIGATION OF ORTHOGONAL CULVERTS (CORTCUL)

by

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March 1981

Final Report

A report under the Computer-Aided Structural Engineering (CASE) Project

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Contract No. DACW39-80-M-0334

Monitored by Automatic Data Processing Center
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF ENGINEERS
WASHINGTON, D.C. 20314

REPLY TO
ATTENTION OF:

DAEN-CWE-DS 13 March 1981

SUBJECT: Instruction Report K-81-7, User's Guide: Computer Program for Design or Investigation of Orthogonal Culverts 'CORTCUL)

All Corps Elements with Civil Works Responsibilities

1. The subject user's guide documents a computer program named CORTCUL that can be used for designing and reviewing reinforced concrete culverts with a layout of members connected by orthogonal joints. The program specifications for CORTCUL were developed by the Computer-Aided Structural Engineering (CASE) Task Group on Culverts and Conduits. As is the goal with all CASE projects, the intent is to provide an organized, cost-effective approach to making available to the structural engineer applicable computer programs ready for use when the design need arises.

2. Structural engineers will be readily able to tell by the description of the programs and by the examples given in the report of the applicability toward their needs. Detailed documentation of the programs may be obtained from the Engineering Computer Programs Library (ECPL) of the U. S. Army Engineer Waterways Experiment Station (WES) Vicksburg, MS.

3. We strongly encourage the use of these programs where applicable throughout the Corps.

FOR THE CHIEF OF ENGINEERS:

for Jack R. Thompson
LLOYD A. DUSCHA
Chief, Engineering Division
Directorate of Civil Works

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Unclassified

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This user's guide describes a computer program [illegible] be used for design or investigation of orthogonal, [illegible] by either working stress design (WSD) or strength [illegible] (SD) [illegible]. In the design mode, the program determines the required thicknesses and reinforcement areas for given soil loadings and culvert opening sizes. In the investigation mode, material stresses or factors of safety are calculated for specified structural geometries and loadings. The program was developed from

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20. ABSTRACT (Continued)

specifications furnished by the Corps of Engineers' Computer-Aided Structural Engineering (CASE) Task Group on Culverts and Conduits. The program follows as a minimum the procedures outlined in Engineer Manual 1110-2-2902, "Conduits, Culverts and Pipes," dated 3 March 1969.

PREFACE

This user's guide describes an interactive computer program called "CORTCUL" that can be used for design or investigation of orthogonal, reinforced concrete culverts. The program employs either the ACI strength design procedure or the conventional working stress design procedure for all flexure computations. The work in writing the program and the user's guide was accomplished with funds provided to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., by the Civil Works Directorate of the Office, Chief of Engineers, U. S. Army (OCE), under the Computer-Aided Structural Engineering (CASE) Project.

Specifications for the program were provided by members of the CASE Task Group on Culverts and Conduits. The following were members of the Task Group (though all may not have served for the entire period) during the period of development of the program:

Mr. Garland E. Young, Fort Worth District (Chairman)
Mr. Byron E. Bircher, Kansas City District
Mr. Terry Cox, Lower Mississippi Valley Division
Mr. Marion M. Harter, Kansas City District
Mr. George Henson, Tulsa District
Mr. Peter Hradilek, Los Angeles District
Mr. John Leong, Sacramento District
Mr. J. J. Smith, St. Louis District

Responsibility for this user's guide was assigned to a subgroup consisting of Messrs. Smith (Chairman), Cox, Henson, and Hradilek.

The computer program and user's guide were written by Dr. William P. Dawkins, P. E., of Stillwater, Okla., under Contract No. DACW39-80-M-0334 with WES.

The work was managed and coordinated by Dr. N. Radhakrishnan, Special Technical Assistant, Automatic Data Processing (ADP) Center, WES, and Mr. Paul K. Senter, Computer-Aided Design Group, ADP Center. Mr. Donald L. Neumann was Chief of the ADP Center. Mr. Donald R. Dressler was the point of contact in OCE.

Directors of WES during the development of this program were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

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LIST OF FIGURES

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
kips (1000 lb force)	4.448222	newtons
kip (force)-feet	1.355818	newton-metres
kips (force) per square foot	47.880263	kilopascals
pounds (force) per square foot	47.880263	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic foot	16.0184634	kilograms per cubic metre
square feet	0.09290304	square metres
square inches	6.4516	square centimetres

USER'S GUIDE: COMPUTER PROGRAM FOR DESIGN OR INVESTIGATION OF ORTHOGONAL CULVERTS (CORTCUL)

PART I: INTRODUCTION

General

1. This user's guide describes a computer program called "CORTCUL" that can be used for design or investigation of orthogonal, reinforced concrete culverts by either working stress design (WSD) or strength design (SD) procedures. CORTCUL is designated X0024 in the Conversationally Oriented Real-Time Program-Generating System (CORPS) library.* In the DESIGN mode, the program determines the required thicknesses and reinforcement areas for given soil loadings and culvert opening sizes. In the INVESTIGATION mode, material stresses or factors of safety are calculated for specified structural geometries and loadings. The program was developed from specifications furnished by the Corps of Engineers' Computer-Aided Structural Engineering (CASE) Task Group on Culverts and Conduits. The program follows as a minimum the procedures outlined in Engineer Manual 1110-2-2902, "Conduits, Culverts and Pipes," dated 3 March 1969.

Report Organization

2. This report is divided into the following parts:

   a. Part II describes the general culvert and soil system to be designed or investigated by the program.

   b. Part III describes the loads and loading combinations used for design and/or investigation.

   c. Part IV describes the structural model of the culvert used to determine internal forces.

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* Three sheets entitled "PROGRAM INFORMATION" have been hand-inserted inside the front cover of this report. They present general information on the program and describe how it can be accessed. If procedures used to access this and other CORPS library programs should change, recipients of this report will be furnished a revised version of the "PROGRAM INFORMATION."

d. Part V reviews the methods and procedures employed in the DESIGN mode.

e. Part VI discusses the methods and procedures used in the INVESTIGATION mode.

f. Part VII describes the computer program.

g. Part VIII presents example solutions obtained with the program.

Disclaimer

3. As stated above, the program was developed using criteria furnished by the CASE Task Group on Culverts and Conduits. The design procedures and philosophy embodied in the program do not necessarily represent the views of the author.

4. The program has been checked within reasonable limits to assure that the results are accurate within the limitations of the procedures employed. However, there may exist unusual situations which were not anticipated which may cause the program to produce questionable results. It is the responsibility of the user to judge the validity of the results, and no responsibility is assumed for the design or behavior of any structure based on the results of this program.

PART II: THE SYSTEM

General

5. A cross section of the general system used in the development of the computer program is shown in Figure 1. It was assumed that the conditions depicted in Figure 1 permit a planar analysis of a unit slice to be representative of the behavior of the three-dimensional system.

Culvert

6. The culvert, shown in Figure 1, is assumed to be a monolithic reinforced concrete structure possessing the following characteristics:

- a. The thickness of the horizontal roof slab, T(1), is constant throughout the width of the structure.
- b. The two exterior vertical walls have the same thickness, T(2).
- c. All interior vertical walls have the same thickness, T(4).
- d. The horizontal base slab has a constant thickness, T(3), throughout the width of the structure.
- e. The culvert encloses one (1) to nine (9) openings ($1 \leq$ NCELLS ≤ 9).
- f. The height of all cells (RISE) is constant.
- g. In the DESIGN mode the cells are assumed to have the same width (WIDTH(I) = constant).
- h. In the INVESTIGATION mode cell widths may differ.
- i. 45° haunches may be specified at the intersections of vertical and horizontal elements. Haunches of equal size, H, are assumed to exist at every intersection.
- j. The elevation of the invert, ELINV (Figure 1), is assumed to be fixed. Adjustments in member thickness which occur during the DESIGN process may result in variations in the elevations at other locations in the structure.

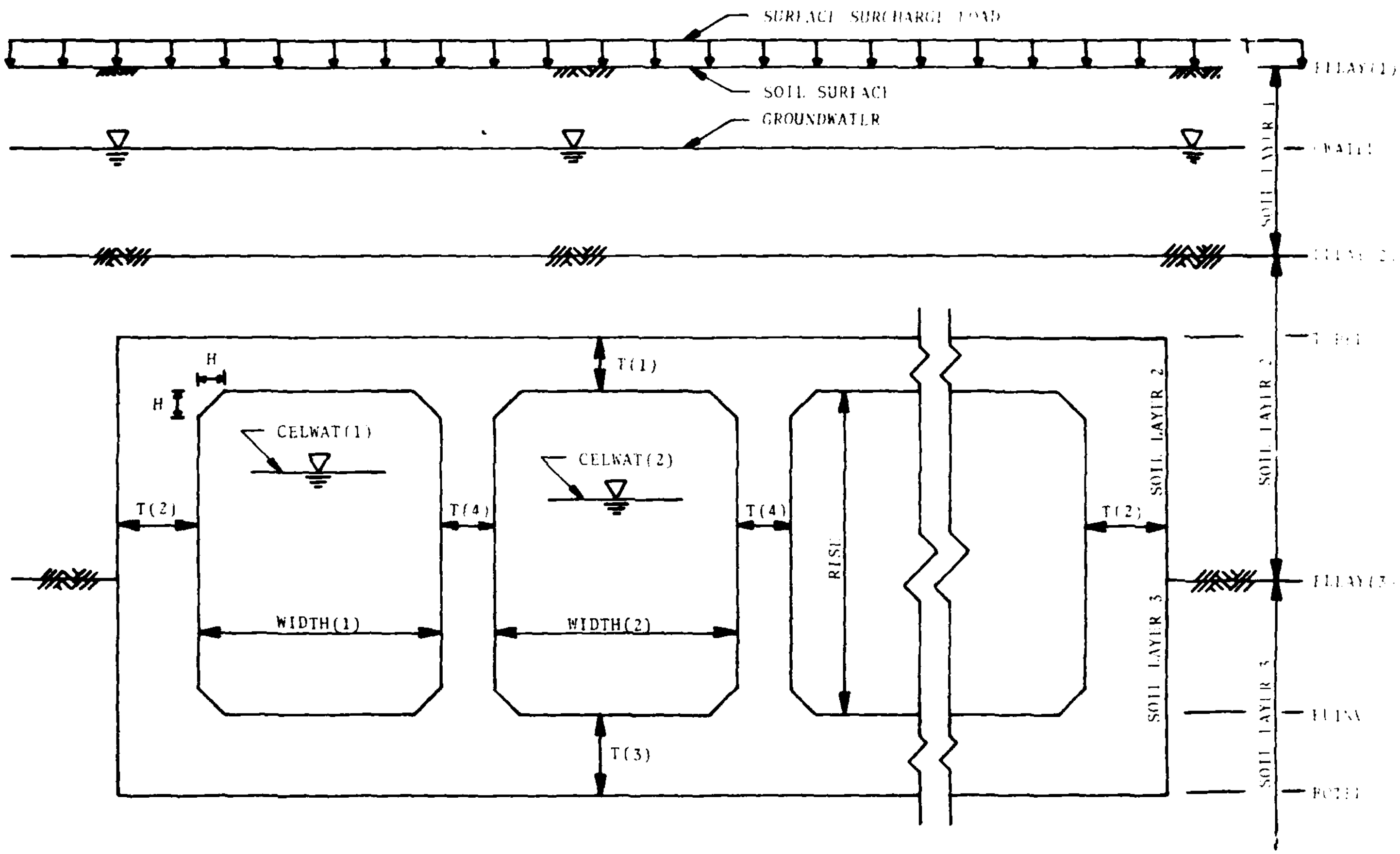

Figure 1. Culvert/soil/water system

Reinforcement

7. Non-prestressed reinforcement is assumed to exist in each element of the culvert. The location and amount of reinforcement depends on the mode--DESIGN or INVESTIGATION--in which the program is operating.

8. In the DESIGN mode the program determines the required area of reinforcement in each element. A singly reinforced cross section is assumed with the location of the reinforcement dictated by the amount of concrete cover provided as input for each surface as follows:

a. Exterior surfaces.

b. Interior surfaces of roof and exterior vertical walls.

c. Interior surface of base.

d. Interior vertical walls (if zero is specified for these walls, the reinforcement is assumed to be at the center of the walls).

9. In the INVESTIGATION mode reinforcement areas are input for each member to be considered. In the INVESTIGATION mode doubly reinforced sections may be described.

Culvert Material Properties

10. The following material properties are provided as input, calculated by the program, or defined internally.

a. Concrete ultimate compressive strength

f'_c (psi) (input)

b. Concrete working stress

$f_{ca} = 0.45\ f'_c$ (calculated)

c. Concrete unit weight

w (pcf) (input)

d. Concrete modulus of elasticity

$E_c = 33\sqrt{w^3\ f'_c}$ (psi) (calculated)

e. Concrete ultimate strain

$\varepsilon'_c = 0.003$ (set)

f. Concrete Poisson's ratio

$\nu = 0.2$ (set)

g. Reinforcement yield strength

f_y (psi) (input)

h. Reinforcement working stress

$f_{sa} = 0.5 f_y$ (calculated, $\leq$ 20 ksi)

i. Reinforcement modulus of elasticity

$E_s = 29 \times 10^6$ (psi)* (set)

j. Modular ratio

$n = E_s/E_c$ (calculated)

Soil

11. The culvert is assumed to be imbedded in the general soil system shown in Figure 1. The soil system is assumed to be composed of one (1) to three (3) horizontal homogeneous layers. Each soil layer is characterized by:

a. The elevation (ft) at the top of the layer, ELLAY ( ), Figure 1.

b. The moist unit weight (pcf).

c. The saturated unit weight (pcf).

12. The effective unit weight of the soil is determined by the program according to the position of the groundwater elevation. For soil above groundwater level the moist unit weight is used. For soil below groundwater level the unit weight of water is subtracted from the saturated soil weight to obtain the effective soil weight.

13. Subsurface soil layers may begin at any elevation. However, the elevation of the top soil layer must be at or above ELINV. The lowest soil layer described is assumed to extend ad infinitum downward.

Water

14. Two water effects are considered by the program.

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* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 6.

Groundwater

15. Groundwater level, GWATEL (Figure 1), may be at any elevation. Groundwater has the dual effect of altering the effective unit weight of submerged soil and of imparting hydrostatic loads on the external surfaces of the culvert.

Internal Water

16. In the DESIGN mode the cells of the culvert are assumed to be empty. In the INVESTIGATION mode effects of internal water are imposed on each of the standard load cases by specifying the elevation of the water level in each cell. If the internal water elevation in a cell is below ELINV, that cell is assumed to be empty. An internal water elevation in any cell above ELINV may result in hydrostatic pressures on all internal surfaces of that cell.

Surface Surcharge Load

17. A uniform surcharge load may be imposed on the ground surface, SURCH (Figure 1). This surcharge load permits accounting for effects on the ground surface such as pool water above a clay blanket, weight of a structural slab or pavement, or weight of rock overburden.

PART III: LOADS ON CULVERT

General

18. Loads acting on the structure are separated into three categories:

   a. Standard Loads--loads imparted by soil, groundwater, surface surcharge, and weight of the structure. The magnitudes and distributions of these loads are determined by the program.

   b. Special Loads--loads acting directly on individual members. These loads are described member by member in the input data.

   c. Internal Water Loads--loads imparted by water in individual cells. The magnitudes and distributions are calculated by the program and superimposed on the Standard Loads.

19. In the DESIGN mode only the Standard Loads are considered. These loads are self-equilibrating in the horizontal direction and do not produce an unbalanced moment resultant.

20. In the INVESTIGATION mode the structure may be subjected to:

   a. Standard loads.

   b. Standard loads with internal water loads.

   c. Special loads with all loads provided as program input.

Standard Loads

21. In the following paragraphs the procedures used to determine the magnitudes and distributions of the loads due to the surface surcharge, soil, water, and structure weight are described. As will be discussed later, the relative magnitudes of these loads may be altered by application of load coefficients. Unit coefficients are assumed in the development below. Loads and distributions are shown schematically in Figures 2, 3, 4, and 5.

Surface Surcharge Load

22. Pressures due to the surface surcharge are uniformly distributed

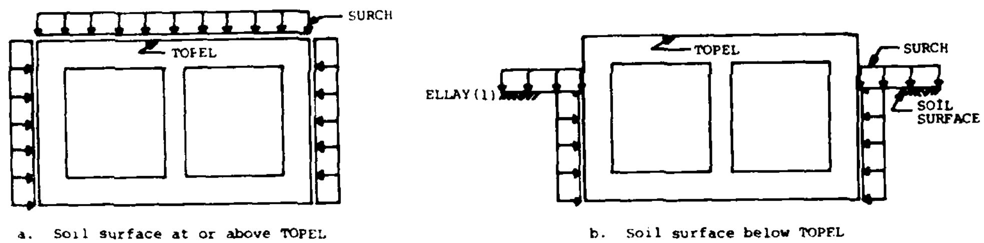


Figure 2. Pressures due to surface surcharge load (see Table 1 for effect of pressure coefficients and load factors)

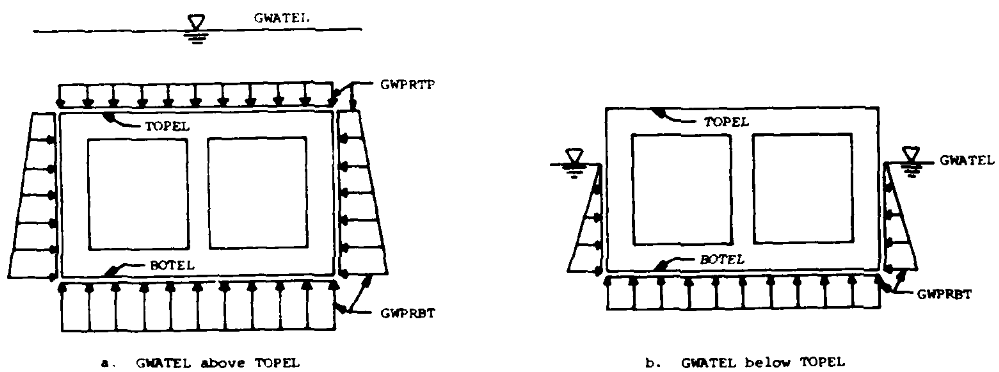
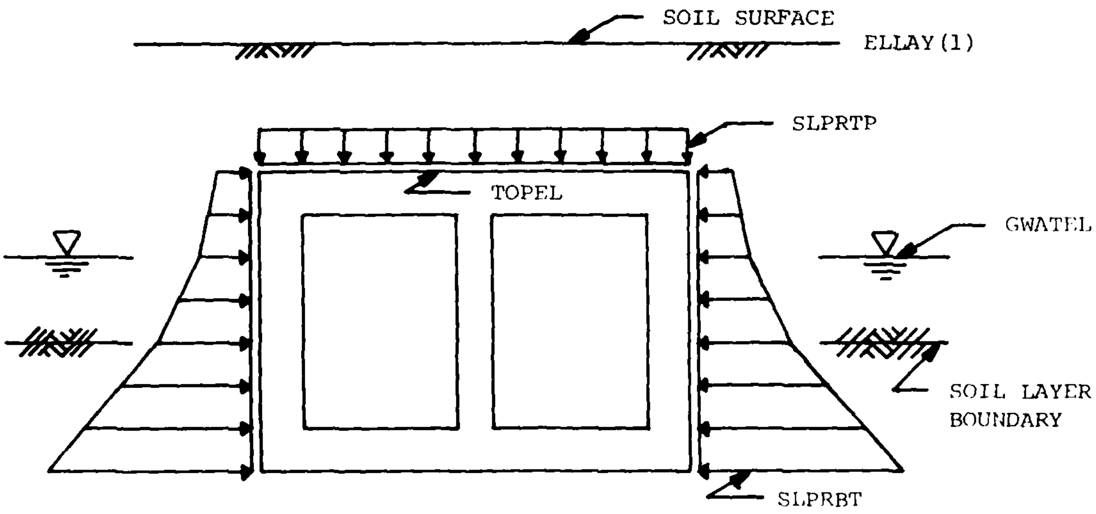
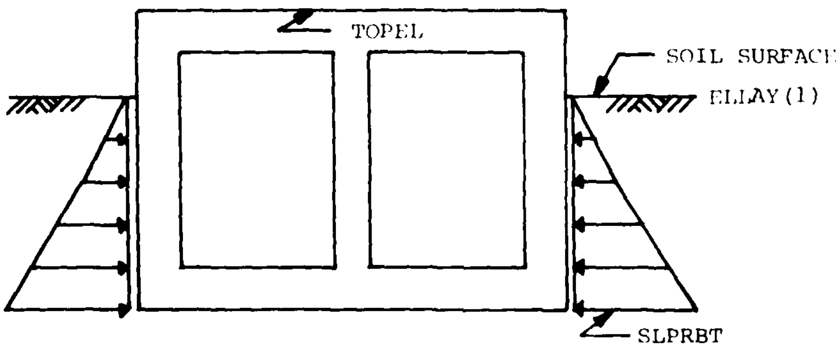


Figure 3. Groundwater pressures (see Table 1 for effect of pressure coefficients and load factors)



a. Soil surface above TOPEL



b. Soil surface below TOPEL

Figure 4. Soil pressures (see Table 1 for effect of pressure coefficients and load factors)

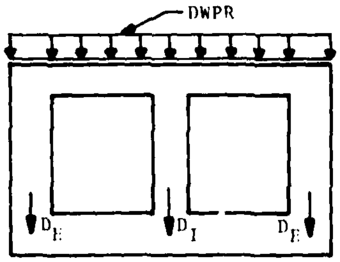
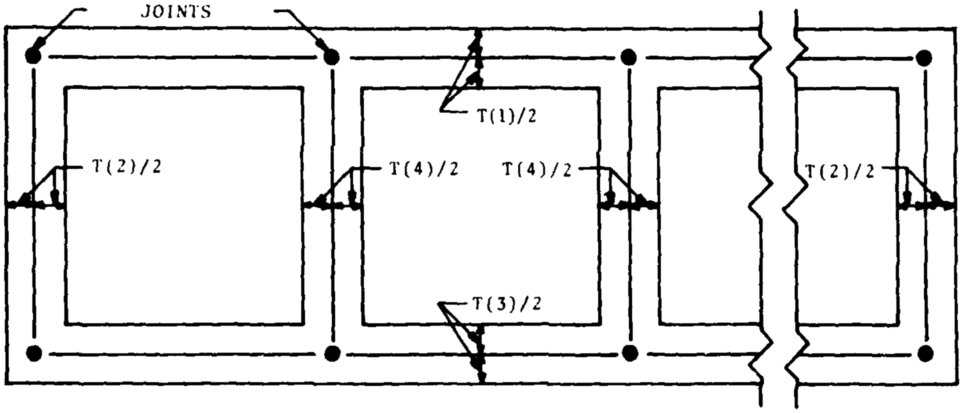
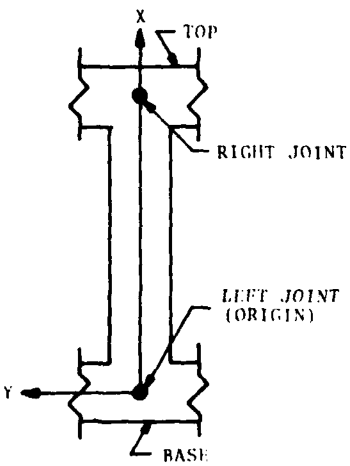


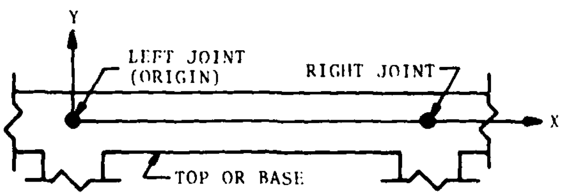
Figure 5. Structure Weight



a. Joint locations



b. Member coordinates for vertical member



c. Member coordinates for horizontal member

Figure 6. Joint locations and member coordinate systems

on the top and external vertical surfaces of the culvert, as shown in Figure 2.

Groundwater

23. The magnitude and distribution of hydrostatic pressure due to groundwater depends on the groundwater elevation, Figure 3.

$$\text{GWPRTP} = (\text{GWATEL} - \text{TOPEL})\cdot\gamma_w$$

$$(\text{GWPRTP} = 0 \text{ if GWATEL} \leq \text{TOPEL})$$

$$\text{GWPRBT} = (\text{GWATEL} - \text{BOTEL})\cdot\gamma_w$$

Soil

24. Vertical and horizontal soil pressures on the top and exterior vertical surfaces, respectively, are equal to the vertical soil pressure due to the total effective soil weight above each point. Vertical soil pressure on the top surface is uniformly distributed, Figure 4. Horizontal soil pressures on the vertical exterior surfaces may vary, as illustrated in Figure 4, depending on the elevations of the groundwater and/or soil layer boundaries.

Structure Weight

25. The weight of the top slab is applied as a uniform load on the top members, as illustrated in Figure 5, where

$$\text{DWPR} = w\cdot T(1)$$

The weights of the vertical walls are applied as concentrated loads, Figure 5, at the "joints" (see section on structure modeling) at the base slab, where

$$D_E = w\cdot T(2)\cdot\text{RISE}$$

and

$$D_I = w\cdot T(4)\cdot\text{RISE}$$

The weight of the base slab is assumed to have no influence on the internal forces in the structure.

Load Coefficients

26. Relative magnitudes of the unit pressures described above may be altered by specifying pairs of vertical and horizontal pressure coefficients, CV, CH, respectively. The combination of pressures altered by these coefficients is referred to as a Standard Load case. Up to four (4) Standard Load cases are permitted. These Standard Load cases allow compliance with the provisions of Reference (5).

Load Factors

27. If the SD method is used, relative magnitudes of the above loads are also amplified for live load and dead load factors, FLL and FDL, respectively. All loads except those due to structure weight are considered to be live loads. Table 1 shows the various effects of Load Coefficients and Load Factors on each component of the Standard Loads.

Special Loads

28. Up to four (4) Special Load cases may be described for the INVESTIGATION mode. These loads are considered separately from any Standard Load cases which may be present. Special loads are applied directly to the members of the culvert and their description is related to a coordinate system defined for each member, as shown in Figure 6. "Joints" of the structural model are defined at the intersections of the centerlines of the vertical and horizontal members, as shown in Figure 6a. A coordinate system is then defined for each member, as shown in Figure 6b. For purposes of describing Special Loads, a member is assumed to extend between the limits shown in Table 2. Eight load types are available for special loads, as shown in Figure 7. Member loads are positive if they act in the positive member coordinate direction. In all cases shown in Figure 7, the dimensions defining member loads must satisfy the following restrictions:

$$L1 \leq D1 \leq L2$$

and

$$D1 < D2 \leq L2$$

where L1 and L2 are the member limits given in Table 2. Several of these

TABLE 1

Load Multipliers

Load Component	Culvert Member	Multiplier WSD	Multiplier SD
Surface Surcharge	Top	1	FLL
	Ext. Vert.	(CH/CV)	(CH/CV)•FLL
Groundwater	All	1	FLL
Soil	Top	CV	CV•FLL
	Ext. Vert.	CH	CH•FLL
Structure Weight	All	1	FDL
Internal Water (Investigation Only)	All	1	FLL
Special Loads (Investigation Only)	All	1	FLL

TABLE 2

Member Limits for Special Load Description

Member	Limits (L1 ≤ x ≤ L2)	
	Left End (L1)	Right End (L2)
Horizontal Member With NCELLS = 1	[-T(2)/2]	[3 T(2)/2 + WIDTH(1)]
Horizontal Member in Left Cell With NCELLS > 1	[-T(2)/2]	[T(2)/2 + WIDTH(1) + T(4)/2]
Horizontal Member in Interior Cell I With NCELLS > 1	0	[T(4) + WIDTH(I)]
Horizontal Member in Right Cell With NCELLS > 1	0	[T(4)/2 + WIDTH(NCELLS) + T(2)]
Vertical Member	[-T(3)/2]	[T(3)/2 + RISE + T(1)]

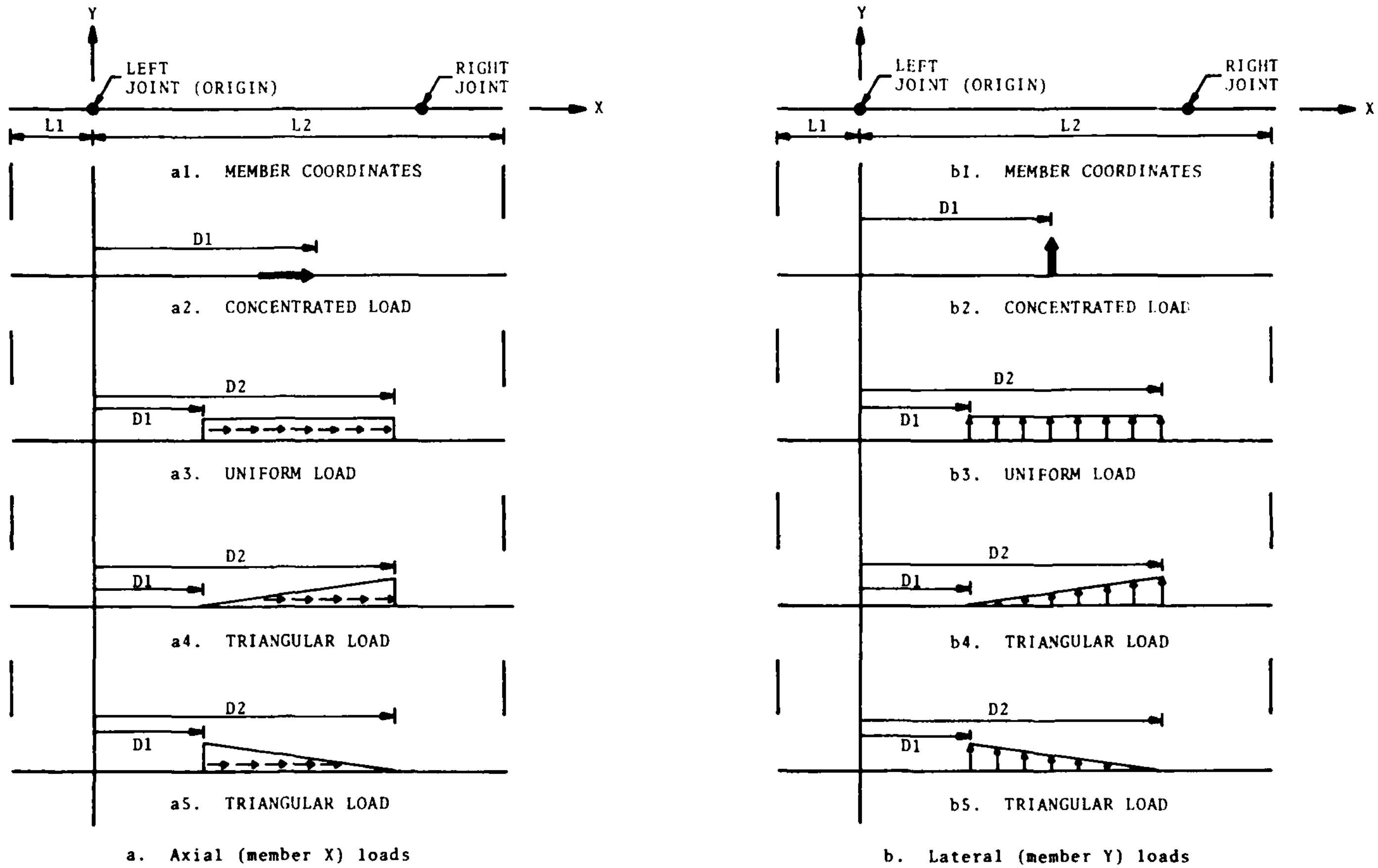


Figure 7. Special member loads

distributions may be applied to a single member. Loads applied in the member x direction are assumed to act along the member centerline.

Special Load Coefficients and Factors

29. The loads described for each Special Load case are used without alteration for WSD. All Special Loads are assumed to be live loads and are multiplied by FLL (see Table 1) for SD.

Unbalanced Loads

30. As stated previously, Standard Loads for DESIGN are self-equilibrating in the horizontal direction and have no resultant moment. However, a vertical force equal to the resultant of soil, water, and structure weight loads must be applied to provide for vertical equilibrium. Special Loads may be described which produce unbalanced horizontal, vertical, and moment resultants. In addition, when internal water is present and is combined with the Standard Loads in the INVESTIGATION mode, the combination may produce unbalanced vertical and moment resultants. The manner in which forces are added to place the structure in total equilibrium depends on the mode--DESIGN or INVESTIGATION--in which the program is operating as described below.

Reactions for DESIGN

31. Only Standard Loads are used in the DESIGN mode, hence only a reaction equal to the resultant of the vertical loads due to soil, water, and structure weight is required. The magnitude of this reaction depends on the load coefficients described for each Standard Load case as well as on the Method--WSD or SD--employed. The equilibrating reaction for the resultant for each Standard Load case in the DESIGN mode is assumed to be provided by a distributed foundation reaction acting on the base of the structure. Three (3) options are provided for describing the distribution of the base reaction, as shown in Figure 8. The user selects which distribution is to be used by providing values of two parameters I and J. The values of I and J indicate the relative magnitudes of the pressures at the edge and centerline, QE and QCL, respectively, as shown in Figure 8. Determination of QE and QCL required to equilibrate the resultant V of the soil, water, and structure weight is shown in Table 3.

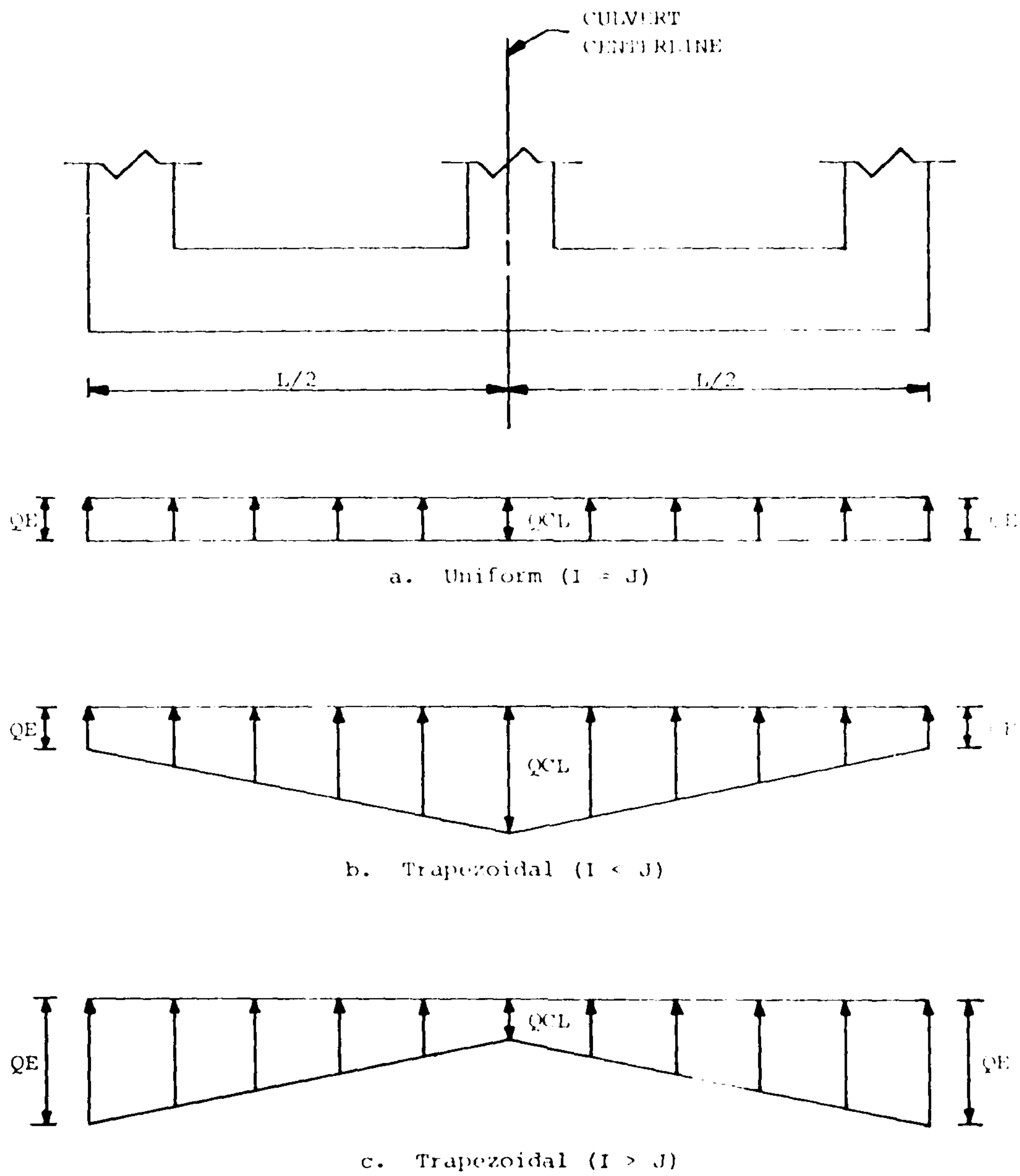


Figure 8. Base reaction for design

TABLE 3

Reaction Distribution for Design

Parameters I and J	Base Reaction Distribution	Edge Reaction Pressure QE	Centerline Reaction Pressure QCL
I = J	Uniform, Fig. 8a	QE = V/L*	QCL = V/L
I = 0, J > 0	Triangular, Fig. 8b	QE = 0	QCL = 2V/L
I < J	Trapezoidal, Fig. 8b	QE = QCL•I/J	QCL = 2V/(L•[1 + I/J])
I > 0, J = 0	Triangular, Fig. 8c	QE = 2V/L	QCL = 0
I > J	Trapezoidal, Fig. 8c	QE = 2V/(L•[1 + J/I])	QCL = QE•J/I

*V = vertical resultant of soil, water, and structure weight Standard Loads.

L = total width of culvert.

Reactions for INVESTIGATION

32. In the INVESTIGATION mode combinations of Standard Loads and internal water, or Special Loads, may produce unbalanced horizontal, vertical, and moment resultants. Prior to solution, four (4) resultants for each load case are established:

H = resultant of all horizontal forces;

HM = resultant moment, about the lower lefthand joint (Figure 6a), of all horizontal forces;

V = resultant of all vertical forces; and

VM = resultant moment, about the culvert centerline, of all vertical forces.

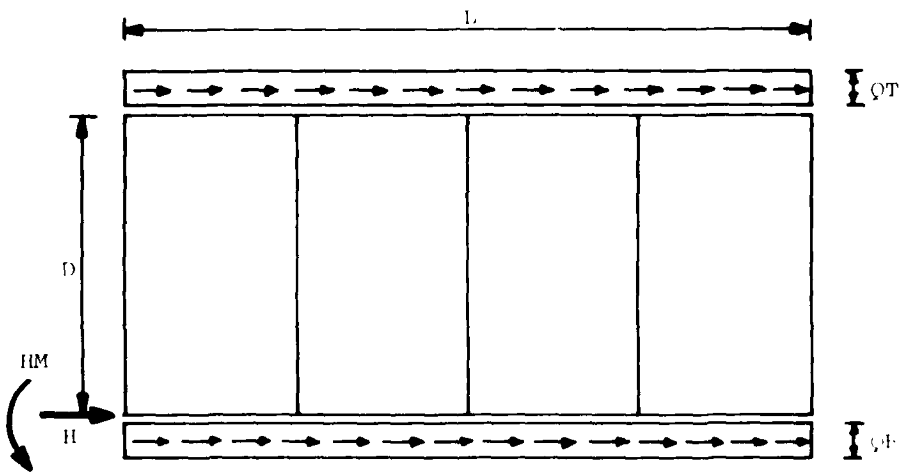
When unbalanced resultants are encountered, it is assumed that equilibrants of these unbalanced resultants are produced by forces acting only on the horizontal members of the culvert as described below. The user has the option of specifying self-equilibrating loads on the structure via the Special Load cases, in which case no additional reactions are necessary.

Reactions for H and HM

33. Unbalanced resultants, H and HM, due to horizontal loads are equilibrated by uniformly distributed horizontal forces on the top and bottom members of the culvert, as shown in Figure 9.

Reactions for V and VM

34. Unbalanced resultants, V and VM, due to vertical loads are equilibrated by vertical distributed forces acting on the horizontal members of the culvert. It is implicitly assumed that these reactions are due to pressures exerted on the culvert by the surrounding soil; hence only compressive reactions are permitted. Consequently, the reaction force may be applied to either the top or bottom of the culvert or to both, depending on the magnitudes and directions of V and VM. The extent of the reaction distribution over the top or bottom surfaces depends on the location of a single force equivalent to the combination of V and



$$D = [T(1) + T(3)]/2 + RISE$$

$$QT = HM/[L*D]$$

$$QB = -[H/L + QT]$$

Figure 9. Reactions for unbalanced horizontal forces for investigation (all directions shown positive)

VM. The various reaction distributions and magnitudes used in the program are shown in Figure 10.

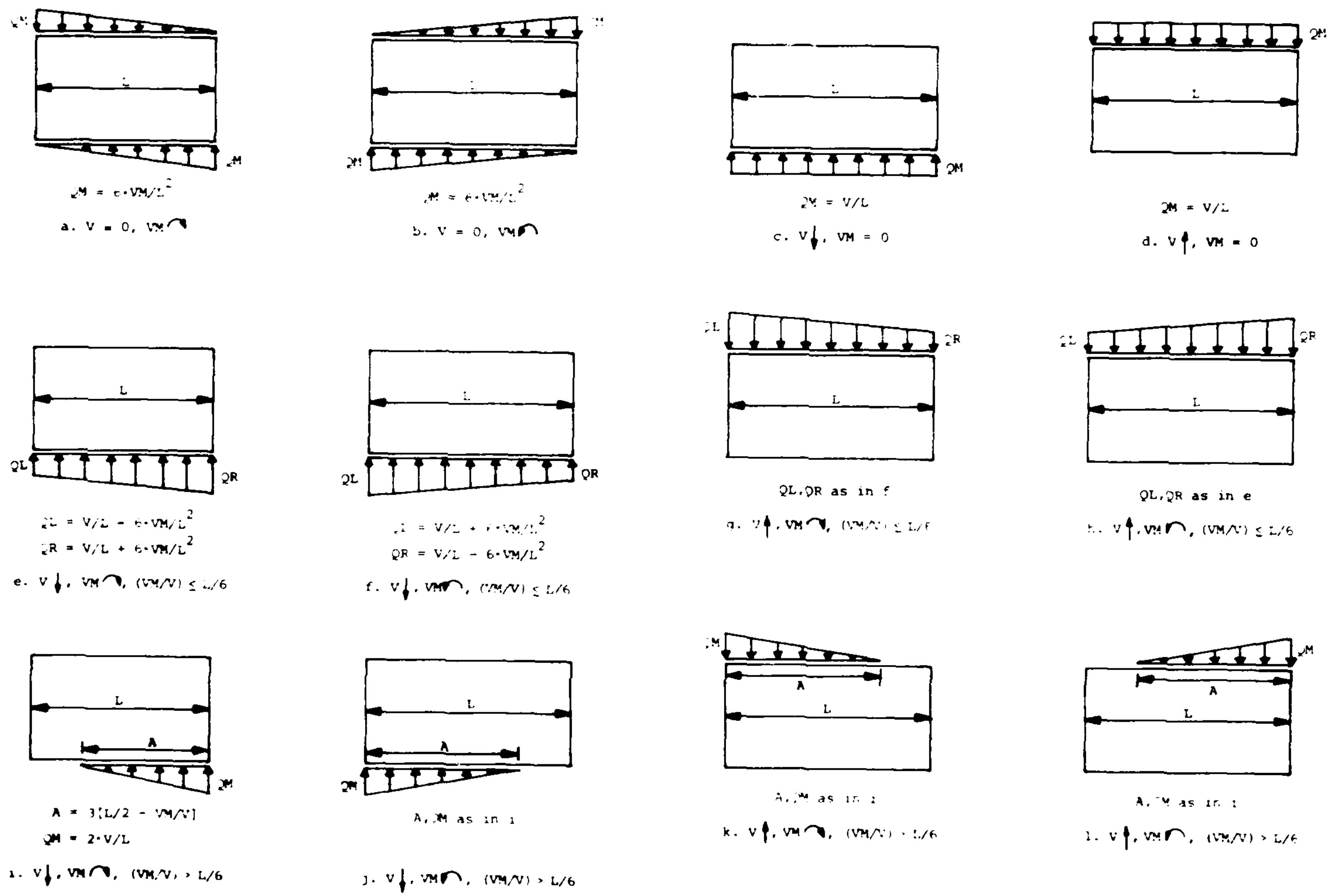


Figure 10. Reactions for unbalanced vertical forces for investigation

PART IV: STRUCTURAL MODELING AND ANALYSIS

General

35. The one-foot slice of the culvert is assumed to behave as a linearly elastic, plane frame structure. A matrix stiffness method modified to account for conditions at the intersections of the members is used to analyze the structure. This method includes the effects of translations and rotations on the internal axial forces, shears, and bending moments. The effects of distortions due to shear stresses are included in the assessment of member force-displacement relationships. The stiffness method is well documented and only a summary description is provided below.

Structural Modeling

36. The culvert slice is reduced to an assemblage of line frame members which lie along the centerlines of the culvert walls and slabs. Joints are defined at the intersections of members. Joint and member numbers used in the program are shown in Figure 11. Each joint in the structure undergoes three displacement components:

- u - translation in the global x direction
- v - translation in the global y direction
- θ - rotation (positive counterclockwise).

Member Description

37. Each member in the frame is assigned a local coordinate system as described previously, Figure 6, and is assumed to extend between the limits defined in Table 2. As described in References 1 and 4, finite member size near the joints is accounted for by assuming infinite axial and flexural stiffnesses to portions of the members in the vicinity of the joints. Flexible and rigid member representations are illustrated in

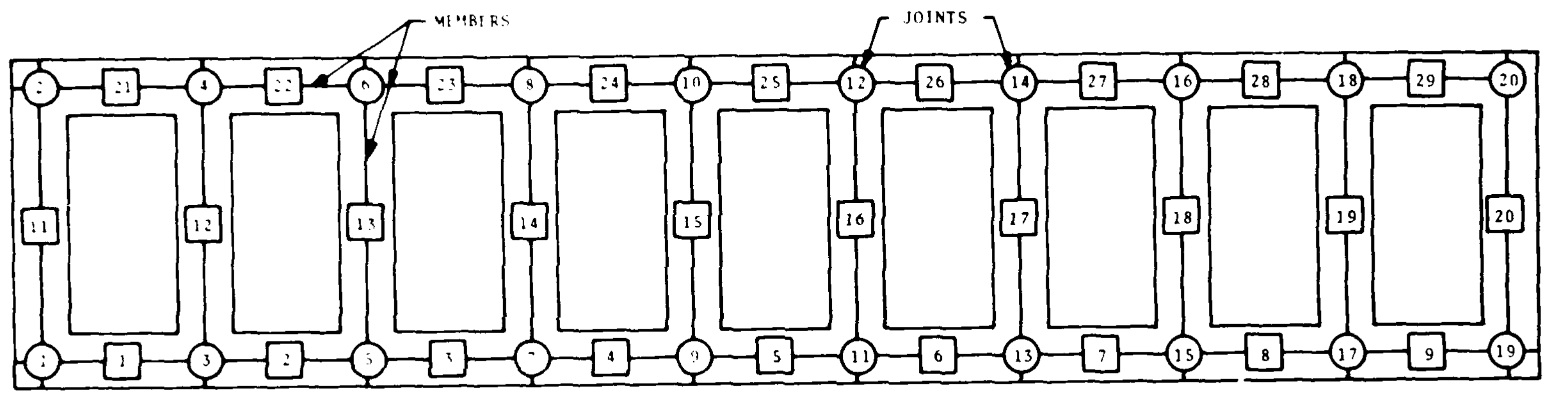


Figure 11. Joint and member numbers

Figure 12. The lengths of these rigid portions beyond the joints associated with each member are established from the thicknesses of the walls and slabs of the culvert (see Figure 12 and Table 2). The procedure recommended in Reference 1 is used for calculating the lengths, ℓ_1 and ℓ_2 (Figure 12b), of the rigid portions between the joints. This procedure is shown in Figure 13. Each member then consists of two rigid portions and a flexible length between joints; members connected to external corner joints also contain rigid sections between the joint and the exterior surface of the structure.

Member Forces at Joints

38. Free body diagrams of various parts of a typical member are shown in Figure 14 with force and displacement components shown in the member coordinate directions. The forces at the joints in the external rigid sections are unaffected by joint displacements. Forces at the ends of the internal portion are composed of two parts: those due to joint displacements and those due to member loads applied between joints. Determination of the contribution of applied member loads to the internal end forces (fixed end forces), including the effects of the rigid lengths is illustrated in Reference 1. The part of the internal end forces resulting from joint displacements is related to the rigid and flexible lengths of the member, as shown in Figure 15.

Joint Displacements

39. Equilibrium analysis of the joints of the structure subjected to all member forces results in a set of simultaneous equations (3n equations for a structure with n joints) of the form

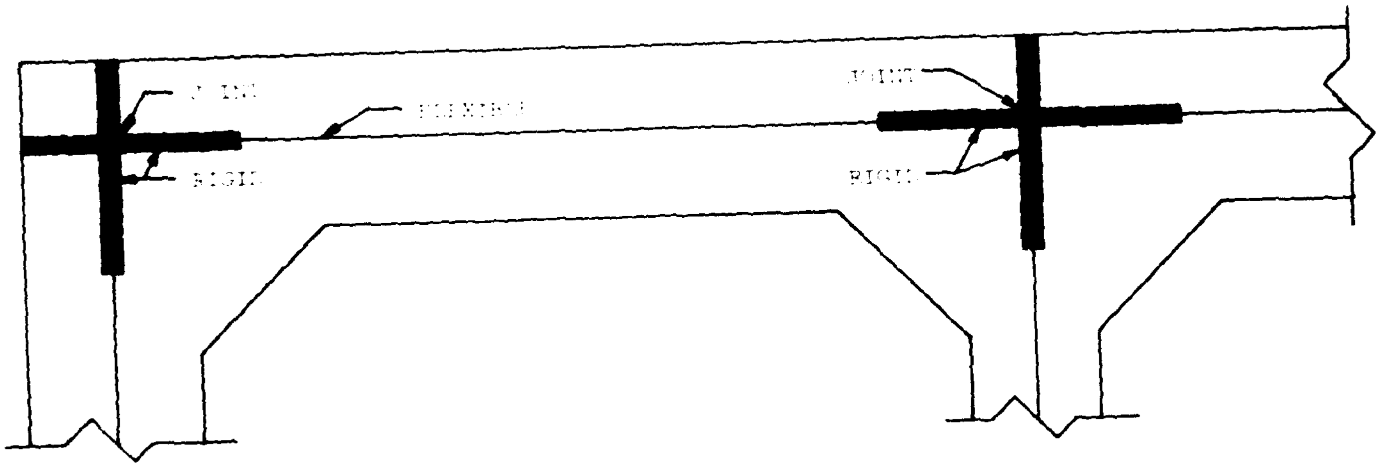
$$F = [K] [illegible]$$

where

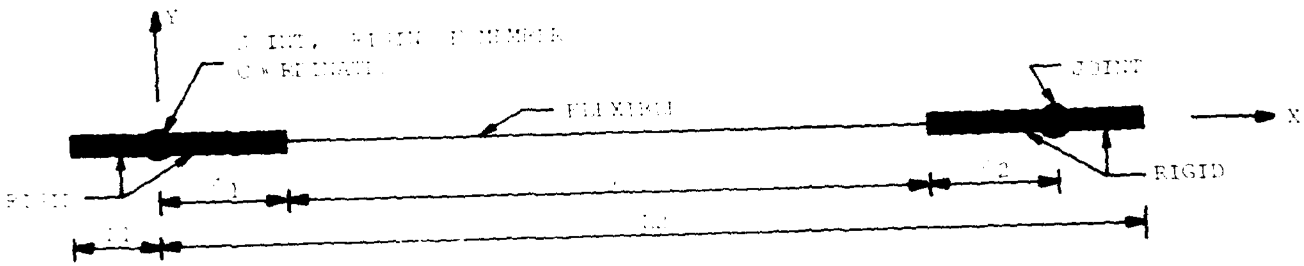
F = (3n x 1) matrix equal to sum of member fixed end forces, forces on external rigid member segments, and weight of vertical members (see paragraph [illegible], section [illegible]);

[illegible] = (3n x 3n) structure stiffness matrix [illegible] member force-displacement relationships; and

[illegible] = (3n x 1) matrix of joint displacements.



a. Flexible and rigid segments



b. Notation for flexible and rigid member segments

Figure [illegible]. Flexible and rigid representation of culvert

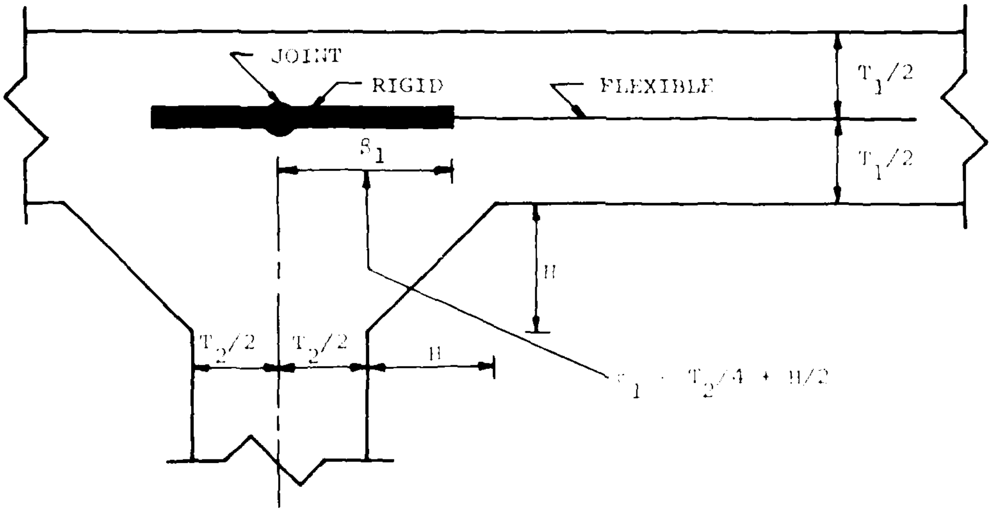


Figure 13. Member rigid lengths by Reference (1)

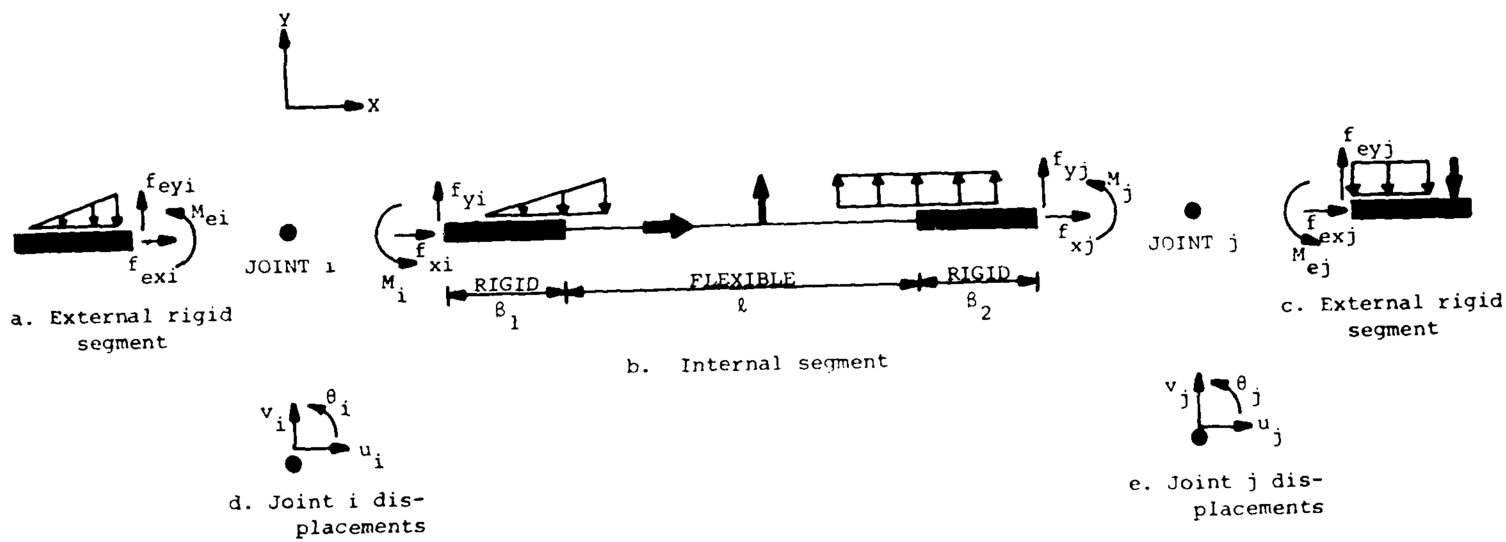
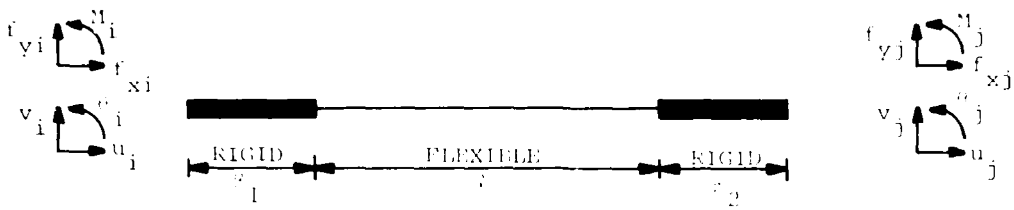


Figure 14. Member free body diagrams



$$
\begin{Bmatrix} f_{xi} \\ f_{yi} \\ m_i \\ f_{xj} \\ f_{yj} \\ m_j \end{Bmatrix}
=
\begin{bmatrix}
k_1 & 0 & 0 & -k_1 & 0 & 0 \\
0 & k_2 & k_3 & 0 & -k_2 & k_4 \\
0 & k_3 & k_5 & 0 & -k_3 & k_6 \\
-k_1 & 0 & 0 & k_1 & 0 & 0 \\
0 & -k_2 & -k_3 & 0 & k_2 & -k_4 \\
0 & k_4 & k_6 & 0 & -k_4 & k_7
\end{bmatrix}
\begin{Bmatrix} u_i \\ v_i \\ \theta_i \\ u_j \\ v_j \\ \theta_j \end{Bmatrix}
$$

Modulus of elasticity = E

Member thickness = T

Section moment of inertia (unit slice) = $I = T^3/12$

$\phi = 2.88\ (T/\ell)^2$

$k_1 = EI/\ell$

$k_2 = 12EI/\ell^3/(1 + \phi)$

$k_3 = 6EI(1 + 2\beta_1/\ell)/\ell^2/(1 + \phi)$

$k_4 = 6EI(1 + 2\beta_2/\ell)/\ell^2/(1 + \phi)$

$k_5 = EI[12\beta_1(1 + \beta_1/\ell)/\ell + 4 + \phi]/(1 + \phi)$

$k_6 = EI[6(\beta_1 + \beta_2)/\ell + 12\beta_1\beta_2/\ell^2 + 2 - \phi]/(1 + \phi)$

$k_7 = EI[12\beta_2(1 + \beta_2/\ell)/\ell + 4 + \phi]/(1 + \phi)$

Figure 15. Member force-displacement relationship

This set of simultaneous equations is solved for the joint displacements.

Member Internal Forces

40. When a solution for joint displacements has been obtained, the total end forces on a member between joints may be evaluated as the sum of the forces due to joint displacements and the fixed end forces. The total member end forces and the member loads are then used to calculate axial forces, shears, and bending moments at other points in the member.

Interval Spacing for Member Forces

41. Member internal forces for either DESIGN or INVESTIGATION are calculated at intervals along each member as follows:

Roof Members

- a. At the structural joints.
- b. At the faces of perpendicular members.
- c. At the ends of haunches.
- d. At the centerline of the clear span.
- e. At one (1) or two (2) additional points between haunch and centerline of clear span.
- f. At the points of application of each concentrated load for Special Load cases.
- g. At the beginning and end of each distributed load for Special Load cases.
- h. At the beginning and/or end of the distributed reaction for each Special Load case.

Exterior Vertical Members

- a. Same as for roof members (a through g).
- b. At the elevation of each soil layer boundary intersecting a vertical member.
- c. At the elevation of the groundwater, if groundwater intersects the member.
- d. At the level of internal water in the adjacent cell, if internal water elevation intersects the member.

Interior Vertical Members

a. Same as for roof members (a through g).

b. At the elevation of internal water in cells to either side of the member.

Base Members

a. Same as roof members (a through h).

b. At the location of the apex of nonuniform base reaction for DESIGN (if apex falls within the span of the member).

PART V: DESIGN

PART V-A: DESIGN ITERATIONS

General

42. In the DESIGN mode the computer program selects, by either WSD or SD procedures, thicknesses and reinforcement areas for the roof, exterior walls, base, and interior walls required to sustain one or more standard load cases and to satisfy limiting thicknesses and reinforcement areas provided as input. The general iterative procedure described below required to arrive at final design dimensions is the same regardless of the method, WSD or SD, employed. Details associated with the WSD or SD methods are described subsequently.

Initial Conditions

43. As discussed in Part III, the loads acting on the structure depend on the structure dimensions. To begin the iterative process, the dimensions of the structure are established with all members having the minimum allowable thicknesses provided as input.

Loads and Member Forces

44. Trial member thicknesses allow the soil and water loads and appropriate base reactions for each standard load case to be determined. A stiffness analysis, Part IV, is performed for the trial geometry, and the bending moments, shears, and axial forces are calculated at the intervals described in Part IV for each member for each load case.

Flexure Calculations

45. Each member is analyzed for the bending moment, shear, and axial force produced at each point by each load case. If the trial thickness satisfies all flexural stress or flexural strength and reinforcement

requirements at every point, no alteration of that member is required. If one or more members fail to satisfy flexural requirements, the control thickness (roof, exterior walls, base, or interior walls) corresponding to the delinquent member is increased by one (1) inch, and the flexure investigation is repeated starting with loads and members forces described in paragraph 44 above.

Shear Calculations

46. After a trial geometry is established which satisfies all flexure requirements for all load cases, the structure is investigated for shear strength. If one or more members fail to meet shear strength requirements, the control dimension associated with the delinquent member is increased by one (1) inch, and the entire process beginning with loads and member forces, paragraph 44 above, is repeated. A complete cycle through flexural and shear computations is defined as one design iteration. The program will perform twenty (20) iterations without interruption. If a final design is not achieved, the user is offered the option to continue for additional iterations or to examine the results from the last iteration performed.

Reinforcement Areas

47. Reinforcement areas are calculated for final design thicknesses which satisfy both flexure and shear requirements. Although only a singly reinforced section is used for design calculations, multiple load cases may require reinforcement in both faces of a member at a single location. The maximum reinforcement area required in each face at each point is reported for the final design. If zero reinforcement is calculated at a point, the program reports "MIN" area at that location according to the sign of the bending moment.

PART V-B: WORKING STRESS DESIGN (WSD) FOR FLEXURE

General

48. Figure 16 shows a typical cross section, strain and stress diagrams, and the notation used for WSD. Also shown are stress and strain relationships for the assumed linearly elastic behavior. The cross section width, b, is equal to one (1) foot; the reinforcement cover, d_c, is provided as input; and the section depth, h_i, is the trial depth used to establish forces P and M as discussed in Part V-A. If the trial depth, h_i, is insufficient to satisfy all requirements outlined below, the section depth is increased by one (1) inch.

Uncracked Section

49. If the eccentricity, e (Figure 16), is less than or equal to $h_i/6$, then the entire cross section will be in compression. Because compression reinforcement is excluded from design consideration, a plain concrete section must carry the applied load and moment. The maximum stress in the concrete for this case is obtained from

$$f_c = \frac{P}{bh} + \frac{M(h/2)}{(bh^3/12)}$$

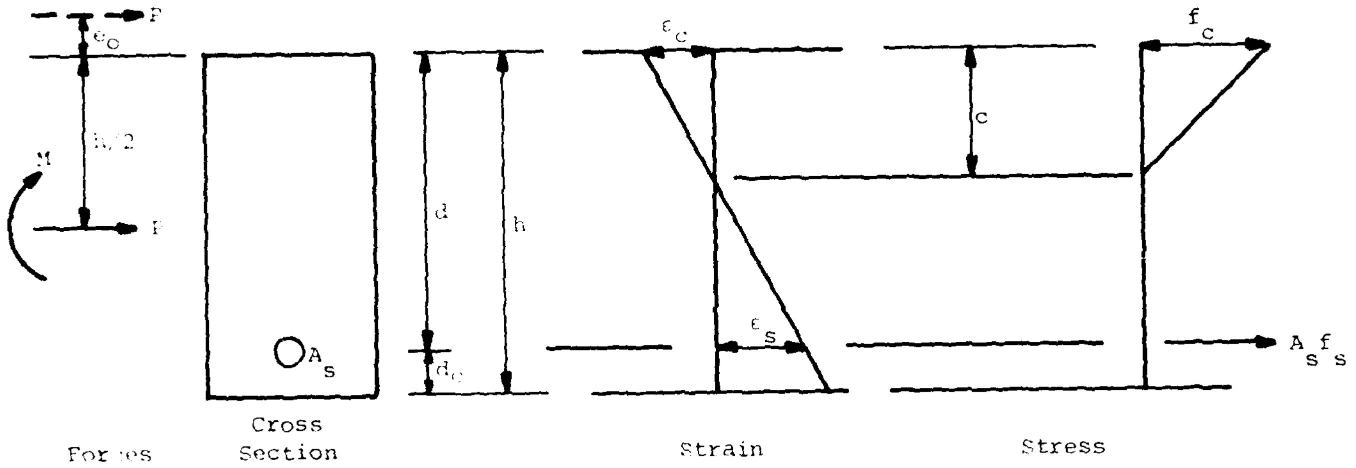
or

$$f_c = \frac{P}{bh} [1 + \frac{6e}{h}] \qquad \text{(V-B.1)}$$

50. If f_c is less than or equal to the allowable concrete stress f_{ca} and the axial force P is less than or equal to $P_A = 0.2125$ bh (Reference 2), trial depth, h_i, is sufficient and no further calculations are required. However, if f_c is greater than f_{ca} or P is greater than P_A, the section depth is increased by one (1) inch.

Cracked Section

51. When the eccentricity, e, is greater than $h_i/6$, a fully cracked



$e = M/F$

$e_o = e - h/2$

$c = [\varepsilon_c/(\varepsilon_c + \varepsilon_s)]d$

$\varepsilon_c = c/(d - c)\varepsilon_s$

$\varepsilon_s = [(d - c)/c]\varepsilon_c$

$n = E_s/E_c$

$f_s = [n(d - c)/c]f_c \le f_{sa}$

$f_c = [c/(d - c)]f_s/n \le f_{ca}$

Figure 16. Notation for design with WSD

section must satisfy simultaneously the conditions: $f_c \leq f_{ca}$; $f_s \leq f_{sa}$; and $A_s \leq A_{sm}$; where f_{sa} is the allowable tensile stress in reinforcement; A_s is the required reinforcement area; and A_{sm} is the smaller of the maximum allowable reinforcement area provided as program input or the reinforcement required for balanced design under flexure alone.

52. The trial depth is initially assumed to contain the maximum allowable reinforcement area A_{sm}. Under this assumption material stresses are obtained as follows (see Figure 16 for notation):

a. Location of neutral axis from summation of moments about P at e_o

$$c^3 + 3e_o c^2 + 6n\, A_{sm}\, (d + e_o)(c - d)/b = 0 \qquad \text{(V-B.2)}$$

Neutral axis is located by smallest, real positive root of Equation (V-B.2).

b. Concrete stress from summation of axial forces

$$f_c = P/[bc/2 - n(d - c)\, A_{sm}/c] \qquad \text{(V-B.3)}$$

c. Reinforcement stress from strain compatibility

$$f_s = [n(d - c)/c]\, f_c \qquad \text{(V-B.4)}$$

53. If either $f_c > f_{ca}$ or $f_s > f_{sa}$, the section depth is increased by one (1) inch.

PART V-C: STRENGTH DESIGN (SD) FOR FLEXURE

General

54. A typical cross section, with stress and strain diagrams and notation, is shown in Figure 17. The cross section has b equal to one (1) foot; the reinforcement cover, d_c, is provided as input; and the section depth, h_i, is the trial depth used to establish forces P and M, Part V-A.

Maximum Permissible Reinforcement Area

55. Maximum permissible reinforcement area, A_{sm}, for SD must satisfy two requirements.

a. $A_{sm} \leq A_{smax}$ provided as input.

b. $A_{sm} \leq R_{max} A_{sb}$, where A_{sb} is the reinforcement area which would produce balanced (Reference 2) conditions under flexure without axial load; and R_{max} is a permissible reinforcement ratio provided as input.

56. For balanced conditions under flexure without axial load (see Figure 17)

$$a = \beta_1 d \varepsilon_c'/(\varepsilon_c' + \varepsilon_y)$$

where

$$\beta_1 = 0.85 \text{ for } f_c' \leq 4000 \text{ psi}$$

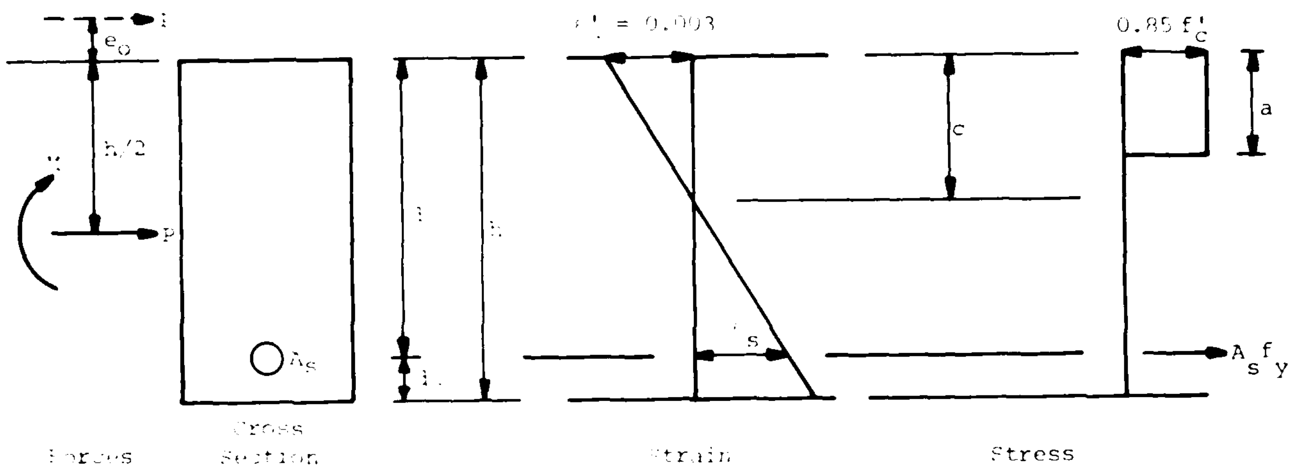
$$\beta_1 = 0.85 - 0.05 (f_c'/1000 - 4) > 0.65 \text{ for } f_c' > 4000 \text{ psi}$$

$$A_{sb} = 0.85 f_c' a/f_y$$

Strength Reduction Factor--ϕ

57. If a nonzero value for strength reduction factor ϕ is provided as input, that value is used without alteration for all calculations. Otherwise, the strength reduction factor ϕ is calculated by the program from (Reference 3)

$$\phi = 0.9 - 2P/(f_c' bh) \geq 0.7 \qquad \text{(V-7..)}$$



$e_o = M/P - h/2$

$c = [\varepsilon'_c/(\varepsilon'_c + \varepsilon_s)]d$

$\varepsilon_s = [(d -$ [illegible]

$f_y = E_s \varepsilon_y$

Figure 17. Notation for Design with SD

Check of Initial Section Depth—h_1

58. For the initial section depth h_1, the dimension of the compression block a is obtained as follows:

a. Summation of moments about P at e_0

$$0.85\ f'_c\ ba\ (a/2 + e_0) - A_{sm}\ f_y\ (d + e_0) = 0 \qquad \text{[illegible]}$$

or

$$a = \sqrt{e_0^2 + 2\ A_s\ f_y\ (d + e_0)/(0.85\ f'_c\ b)} - e_0 \qquad \text{[illegible]}$$

b. Summation of axial forces

$$\phi P_N = \phi[0.85\ f'_c\ ba - A_{sm}\ f_y] \qquad \text{[illegible]}$$

59. If $\phi P_N \geq P$ and $P \leq 0.8\ \phi[0.85\ f'_c\ A_g]$, the initial depth h_1 is adequate and no further calculations are necessary. Otherwise the section depth is increased by one (1) inch.

PART V-D: DESIGN FOR SHEAR

General

60. Shear force at a section is assumed to be carried by shear stresses in the concrete; no vertical shear reinforcement is used. Three different methods are provided for determining the allowable concrete shear stress for either WSD or SD as described below.

Allowable Shear Stress by ACI 318-63

61. ACI 318-63, Reference (2), specifies the following allowable shear stresses v_{ca} for a section subjected to bending M, axial force P, and shear force V.

a. For WSD

$$v_{ca} = \sqrt{f'_c} + 1300\ (A_s/bd)(Vd/M') \qquad \text{(V-D.1)}$$

where $M' = M - P(4h - d)/8$ and $Vd/M' \leq 1$

with

$$v_{ca} \leq 1.75 \sqrt{f'_c} \sqrt{1 + 0.004\ P/(bh)}$$

b. For SD

$$v_{ca} = \phi[1.9 \sqrt{f'_c} + 2500\ (A_s/bd)(Vd/M')] \qquad \text{(V-D.2)}$$

with

$$v_{ca} \leq \phi[3.5 \sqrt{f'_c} \sqrt{1 + 0.002\ P/(bh)}]$$

(Note ϕ is either input value or $\phi = 0.85$ if input value is zero.)

Allowable Shear Stress by University of Illinois Report 440

62. U-of-I report 440, Reference (1), indicates an allowable shear stress given by

$$v_{ca} = \phi[(11.5 - [illegible])\sqrt{f'_c} \sqrt{1 + P/(5\ bh \sqrt{f'_c})}] \qquad \text{(V-D.3)}$$

where ϕ = 0.5 for WSD and ϕ = 1.0 for SD; and ℓ_n = clear span face-to-face of supporting members, neglecting fillets.

Allowable Shear Stress by University of Illinois Report 164

63. U-of-I Report 164, Reference (4), provides an allowable shear stress for working stress design given by

$$v_{ca} = \frac{1}{SF} \frac{11000\ (0.046 + \rho)\left(12 + \frac{P}{V}\right)}{\left(19 + \frac{\ell'}{d}\right)} \sqrt{\frac{f'_c}{4000}} \qquad \text{(V-B.4)}$$

where

- ρ = tension reinforcement ratio, P = axial load;
- V = shear force at point of contraflexure;
- ℓ' = distance between points of contraflexure; and
- SF = safety factor.

Shear Design Options

64. Three shear design options are provided for the design of all exterior members:

Option 1: Design by ACI 63 only, with critical sections at d from face of support. Members with $d > 0.15\,\ell_n$ (i.e., "deep" members, Reference (3)) are not covered by ACI 63. Culverts with members in this category are not accommodated by the computer program for option 1.

Option 2: For $\ell_n/d > 9$, allowable shear stress by ACI 63; for $\ell_n/d \leq 9$, allowable shear stress by U-of-I 440 with critical sections at $0.15\,\ell_n$.

Option 3: (For WSD only.) For $\ell_n/d \geq 9$, allowable shear stress by ACI 63; for $\ell_n/d \leq 5$, allowable shear stress by U-of-I 440; for $5 < \ell_n/d < 9$, allowable shear stress by U-of-I 164 provided two points of contraflexure exist in the clear span of the member with $\ell' \geq 0.6\,\ell_n$ and the allowable shear stress by

U-of-I 164 is less than the allowable by U-of-I 440 for the same ℓ_n/d.

65. All interior vertical walls are designed by ACI 63 exclusively.

Required Depth for Shear

66. The allowable shear stress from the option exercised is compared with the actual shear stress

$$v_c = V/(bd) \tag{V-D.5}$$

where $d = h_i - d_c$. If v_c is less than or equal to v_{ca}, the initial depth h_i is adequate. If v_c is greater than v_{ca}, the section depth is increased by one (1) inch.

PART V-E: FINAL REINFORCEMENT AREAS

General

67. When values have been determined for the four controlling thicknesses (roof, vertical exterior walls, base, and interior walls) which satisfy all flexure and shear requirements, final reinforcement areas are selected.

WSD Reinforcement Area

68. Required reinforcement area for WSD is selected for reinforcement stress $f_s = f_{sa}$ (noting $f_c = [c/(d-c)]\, f_{sa}/n$, Figure 16).

a. Neutral axis is located from summation of moments about A_s

$$\frac{c}{d-c}\,\frac{f_{sa}}{n}\,\frac{bc}{2}\left(d - \frac{c}{3}\right) - P(d + e_o) = 0$$

or

$$c^3 - 3dc^2 - [6Pn\,(d + e_o)/(f_{sa}\,b)]c + 6Pn\,(d + e_o)\,d/(f_{sa}\,b) = 0 \qquad \text{(V-E.1)}$$

The minimum, real, positive root of Equation (V-E.1) locates the neutral axis.

b. Required reinforcement area from summation of axial forces

$$\frac{c}{d-c}\,\frac{f_{sa}}{n}\,\frac{bc}{2} - P - f_{sa}\,A_s = 0$$

or

$$A_s = \frac{bc^2}{2(d-c)n} - P/f_{sa} \qquad \text{(V-E.2)}$$

If A_s from Equation (V-E.2) is less than or equal to zero, only minimum reinforcement is required at that location.

SD Reinforcement Area

69. Required reinforcemert area for SD is calculated as follows, see Figure 17.

<u>a</u>. Compression block dimension <u>a</u> is obtained from summation of moments about A_s

$$0.85\ f'_c\ ba(d - a/2) - P/\phi\ (d + e_o)$$

or

$$a = d - \sqrt{d^2 - 2P\ (d + e_o)/(0.85\ f'_c\ b\phi)} \qquad \text{(V-E.3)}$$

<u>b</u>. Required reinforcement area, A_s, is obtained from summation of axial forces

$$0.85\ f'_c\ ba - P/\phi - A_s\ f_y = 0$$

or

$$A_s = (0.85\ f'_c\ ba - P/\phi)/f_y \qquad \text{(V-E.4)}$$

If A_s from Equation (V-E.4) is less than or equal to zero, only minimum reinforcement at that location is required.

PART VI: INVESTIGATION

PART VI-A: GENERAL

70. In the INVESTIGATION mode the program determines the stresses and/or factors of safety produced in the various components of the structure due to standard loads, combined standard and internal water loads, or to special loads described in Part III. All dimensions of the system are provided as input and no iteration for compatibility of loads and geometry is necessary.

Loads

71. Loads for Standard Load cases are determined from soil, water, and structure dimensions as described in Part III. Because internal water may produce unsymmetric vertical loads, the base reaction for Standard Load cases is limited to the distributions shown in Figure 10c, e, f, i, and j. Special Load cases are treated as described in Part III.

72. A stiffness analysis is performed for each Standard and/or Special Load case and internal shears, bending moments, and axial forces are calculated for each member at the intervals described in Part IV.

Points for Investigation

73. Material stresses and factors of safety due to flexure are calculated and reported for each member to be investigated for cross sections at the left and right ends of the clear span, excluding haunches, and at the centerline of the clear span. If reinforcement areas, provided as input, are inconsistent with the internal forces at any cross section, no attempt is made to calculate stresses or factors of safety at that location. If reinforcement is described for both faces at a location, a doubly reinforced cross section is employed. It should be noted that unusual loading situations may result in a maximum bending moment at locations other than those described above.

PART VI-B: FLEXURE INVESTIGATION WITH WSD

General

74. The typical cross section used for INVESTIGATION with WSD is shown in Figure 18 along with strain and stress diagrams and notation. The general states of loading permitted in the INVESTIGATION mode require consideration of each of the situations described below. Note: Compression stresses in concrete and compression reinforcement are positive; tension stress in tension reinforcement is positive.

Shear Force V Only (M = P = 0)

75. All flexure stresses, f_c, f'_s, and f_s, are zero for this case.

Axial Compression P Only (M = 0)

76. Stresses are obtained as follows:

a. Transformed gross area

$$A_g = bh + (n - 1)(A'_s + A_s) \qquad \text{(VI-B.1)}$$

b. Concrete compressive stress

$$f_c = P/A_g \qquad \text{(VI-B.2)}$$

c. Reinforcement stresses

$$f'_s = (n - 1)\ f_c \qquad \text{(VI-B.3)}$$

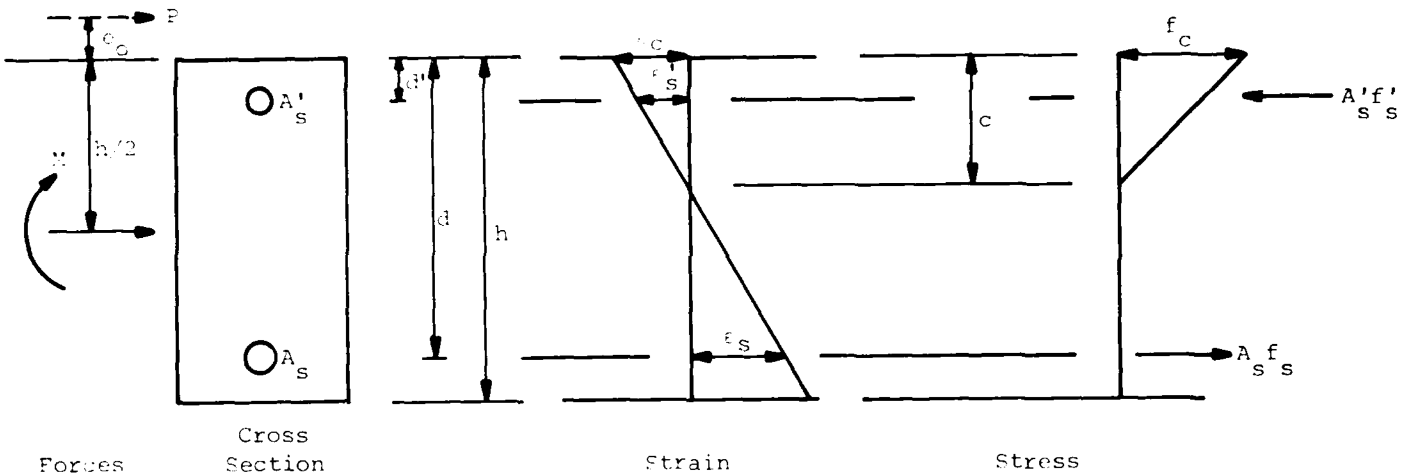
and

$$f_s = -(n - 1)\ f_c \qquad \text{(VI-B.4)}$$

Axial Tension Only (M = 0)

77. The reinforcement alone ($f_c = 0$) is assumed to carry the axial tension force. Stresses in the reinforcement are

$$f'_s = -P/(A'_s + A_s) \qquad \text{(VI-B.5)}$$



$e_o = M/P - h/2$

$c = [\epsilon_c/(\epsilon_c + \epsilon_s)]d$

$\epsilon'_s = [(c - d')/c]\epsilon_c$

$\epsilon_s = [(d - c)/c]\epsilon_c$

$n = E_s/E_c$

$f'_s = [(c - d')/c](n - 1)f_c$

$f_s = [(d - c)/c]nf_c$

$f_c = [c/(d - c)]f_s/n$

Figure 18. Notation for investigation with WSD

and

$$f_s = P/(A_s' + A_s) \qquad \text{(VI-B.6)}$$

Uncracked Section With Axial Compression P and Moment M

78. For all locations with axial compression and bending moment, the initial investigation is made for an uncracked cross section. An uncracked cross section is arbitrarily defined as one for which the concrete stress at the level of the tension reinforcement is compression, i.e., greater than or equal to zero. The effective depth d at the end locations includes the depth of the haunch if the haunch is in compression.

a. Location of elastic centroid

$$c = [bh^2/2 + (n - 1)(A_s' d' + A_s d)]/A_g \qquad \text{(VI-B.7)}$$

b. Moment of inertia of transformed section

$$I_T = bh^3/12 + bh\ (h/2 - c)^2 + (n - 1)\ A_s'\ (c - d')^2 + (n - 1)\ A_s\ (d - c)^2 \qquad \text{(VI-B.8)}$$

c. Concrete stress at level of tensile reinforcement

$$f_{cs} = P/bh - M\ (d - c)/I_T \qquad \text{(VI-B.9)}$$

If f_{cs} is greater than or equal to zero, the section is uncracked.

d. Maximum concrete stress

$$f_c = P/bh + Mc/I_T \qquad \text{(VI-B.10)}$$

e. Compression reinforcement stress

$$f_s' = n[P/bh + M\ (c - d')/I_T] \qquad \text{(VI-B.11)}$$

f. Tension reinforcement stress

$$f_s = -n[P/bh - M(d - c)/I_T] \qquad \text{(VI-B.12)}$$

Cracked Cross Section With Axial Force and Moment

79. If the stress from Equation (VI-B.9) is negative (i.e., tension) for compression axial force or if the axial force is tension, a fully cracked cross section is assumed.

a. Location of neutral axis from summation of moments about P at e_o (see Figure 18)

$$\frac{f_c bc}{2}\left(\frac{c}{3} + e_o\right) + (n-1)\left(\frac{c-d'}{c}\right) f_c A'_s (d' + e_o) - n\left(\frac{d-c}{c}\right) f_c A_s (d + e_o) = 0$$

or

$$c^3 + 3e_o c^2 + \frac{6}{b}\left[(n-1) A'_s (d' + e_o) + nA_s (d + e_o)\right]c - \frac{6}{b}\left[(n-1) A'_s (d' + e_o)d' + nA_s (d + e_o)d\right] = 0$$

(VI-B.13)

Equation (VI-B.13) will not yield positive, real roots if there is excessive axial tension or if no tensile reinforcement is provided, in which case no material stresses are calculated. Otherwise, the smallest, real, positive root locates the neutral axis and material stresses are calculated as follows.

b. Concrete stress from summation of axial forces

$$f_c bc/2 + (n-1)\left(\frac{c-d'}{c}\right) f_c A'_s - n\left(\frac{d-c}{c}\right) f_c A_s - P = 0$$

or

$$f_c = P/\left[bc/2 + (n-1)\left(\frac{c-d'}{c}\right) A'_s - n\left(\frac{d-c}{c}\right) A_s\right]$$

(VI-B.14)

c. Compression reinforcement stress

$$f'_s = (n-1)\left(\frac{c-d'}{c}\right) f_c \qquad \text{(VI-B.15)}$$

d. Tensile reinforcement stress

$$f_s = n \left(\frac{d - c}{c}\right) f_c \qquad \text{(VI-B.16)}$$

Note: If the location of the neutral axis c is such that A'_s is in tension, n is substituted for (n - 1) for all terms associated with the top reinforcement (A'_s) in the above equations.

PART VI-C: FLEXURE INVESTIGATION WITH SD

General

80. The typical cross section used for INVESTIGATION with SD is shown in Figure 19 with strain and stress diagrams and notation. The capability of a cross section to support the applied forces M and P, i.e., "Factor of Safety," is obtained by comparison of the "design" capacity of the cross section ϕP_N, with the applied load P for an eccentricity of the axial load equal to (M/P), or if the applied axial load is zero, by comparison of the "design" moment capacity ϕM_N with the applied moment M. No attempt is made to determine factors of safety for cross sections subjected to axial tension.

Interaction Diagram

81. The generality of loading permitted in the INVESTIGATION mode requires consideration of numerous combinations of axial force P and moment M. The axial force-bending moment interaction diagram used for determining factors of safety is shown in Figure 20. The processes used to develop the interaction diagram are discussed below.

<u>a</u>. Nominal pure moment capacity--M_N

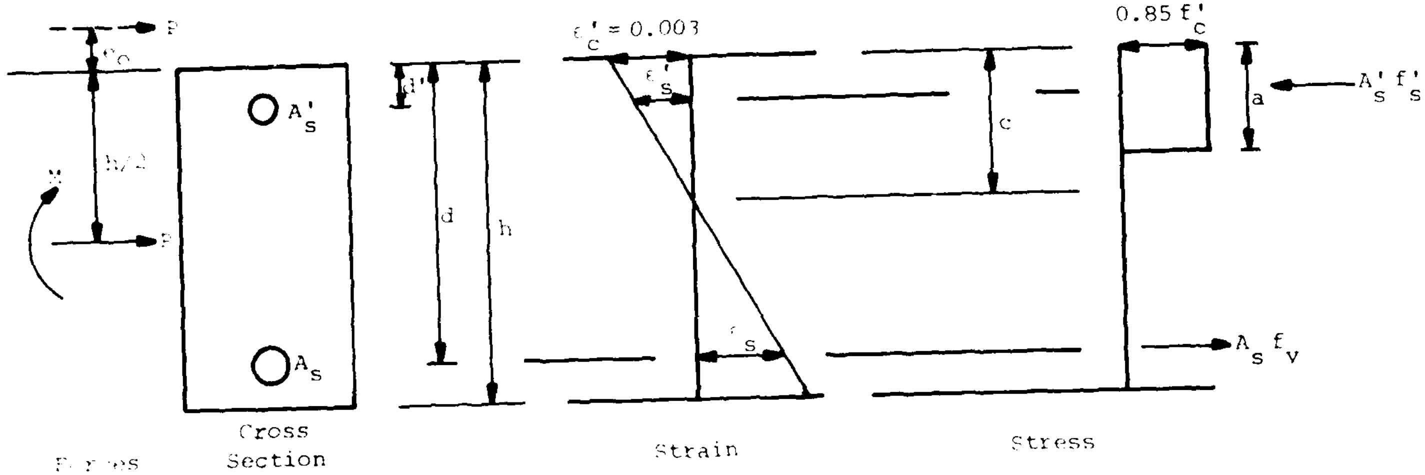
<u>a.1</u> Compression block dimension <u>a</u>, from summation of axial forces = 0: Because the stress in the compression reinforcement must be less than or equal to f_y, a direct solution for the compression block dimension <u>a</u> is not possible if $A'_s \neq 0$. The location of the neutral axis (i.e., c) is adjusted until

$$0.85\, f'_c\, ba + A'_s\, f'_s - A_s\, f_y = 0 \qquad \text{(VI-C.1)}$$

for $f'_s \leq f_y$.

<u>a.2</u> Nominal moment capacity M_N from summation of moments about A_s

$$M_N = 0.85\, f'_c\, ba\, (d - a/2) + A'_s\, f'_s\, (d - d') \qquad \text{(VI-C.2)}$$



$e = M/P$

$e_o = e - h/2$

$c = [\epsilon'_c/(\epsilon'_c + \epsilon_s)]d$

$\epsilon'_s = [(c - d')/c]\epsilon_c$

$\epsilon_s = [(d - c)/c]\epsilon_c$

$f'_s = E_s \epsilon'_s \leq f_y$

Figure 1[illegible]. Notation for investigation with [illegible]

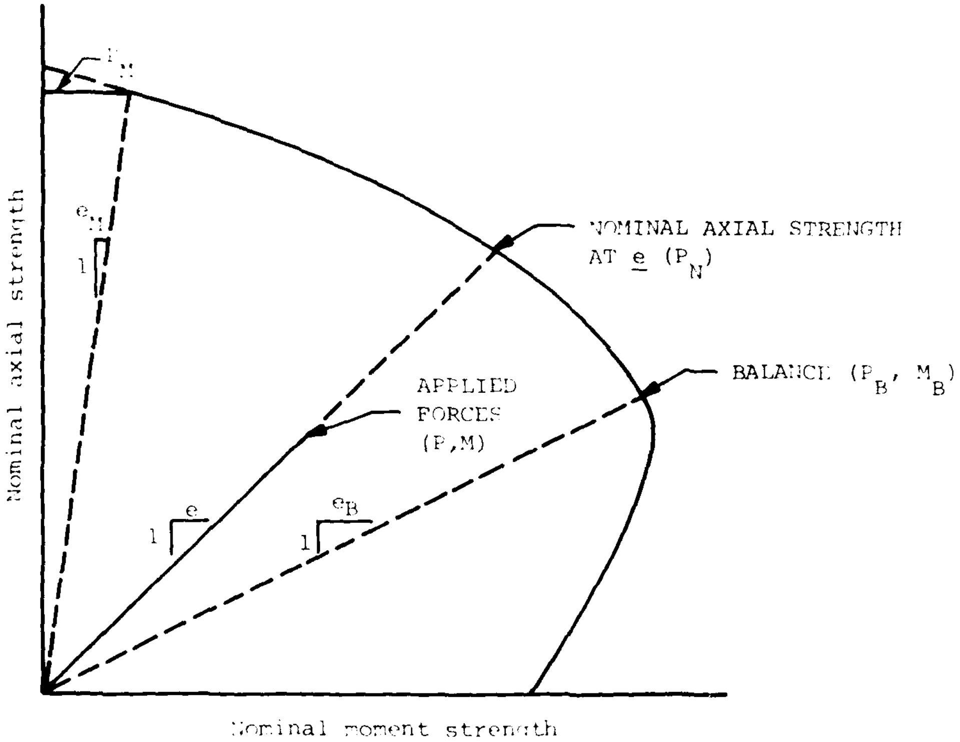


Figure 20. Interaction diagram for investigation with SP

b. Axial force P_B and eccentricity e_B at balance:

b.1 Neutral axis location from strain compatibility with

$\varepsilon_s = \varepsilon_y = f_y/E_s)$

$$c_B = [\varepsilon_c'/(\varepsilon_c' + \varepsilon_y)]d \tag{VI-C.3}$$

b.2 Compression block dimension

$$a_B = \beta_1 c_B$$

where $\beta_1 = 0.85$ for $f_c' \leq 4000$ psi, or $\beta_1 = 0.85 - 0.05$ $(f_c'/1000 - 4) \geq 0.65$.

b.3 Compression reinforcement stress

$$f_s' = E\varepsilon_s' = E_s[(c_B - d')/c_B]\varepsilon_c' \leq f_y$$

b.4 Balance axial force from summation of axial forces

$$P_B = 0.85\ f_c'\ ba_B + A_s'\ f_s' - A_s\ f_y \tag{VI-C.4}$$

b.5 Balance eccentricity from summation of moments about mid-section

$$0.85\ f_c'\ ba_B\ (h/2 - a_B/2) + A_s'\ f_s'\ (h/2 - d')$$

$$+ A_s'\ f_y\ (d - h/2) - P_B\ e_B = 0$$

or

$$e_B = [0.85\ f_c'\ ba_B\ (h/2 - a_B/2) + A_s'\ f_s'\ (h/2 - d')$$

$$+ A_s\ f_y\ (d - h/2)]/P_B \tag{VI-C.5}$$

c. Minimum eccentricity--e_M

c.1 Maximum axial load P_M. Reference (3) limits the maximum axial load on a section to

$$P_M = 0.8\ [0.85\ f_c'\ (bh - A_s' - A_s)$$

$$+ f_y\ (A_s' + A_s)] \tag{VI-C.6}$$

c.2 Minimum eccentricity--e_M. The limitation on axial load to the value from Equation (VI-C.6) implies a

minimum eccentricity, Figure 20, below which the section is to be considered in pure compression.

From summation of axial forces with $P = P_M$

$$0.85\ f'_c\ ba + A'_s\ f'_s - A_s\ f_y - P_M = 0 \qquad \text{(VI-C.7)}$$

The location of the neutral axis (i.e., c, hence a) is adjusted until Equation (VI-C.7) is satisifed with $f'_s \leq f_y$.

The minimum eccentricity e_M is obtained from summation of moments about mid-section

$$e_M = [0.85\ f'_c\ ba\ (h/2 - a/2) + A'_s\ f'_s\ (h/2 - d')$$

$$+ A_s\ f_y\ (d - h/2)]/P_M \qquad \text{(VI-C.8)}$$

Flexure Factor of Safety

82. As stated above, if the applied axial force is tension, no attempt is made to calculate a factor of safety for that location. If the applied axial force is zero, the factor of safety is defined as

$$SF = \phi M_N/M \qquad \text{(VI-C.9)}$$

where M_N = nominal pure moment capacity, M = applied moment, and ϕ = strength reduction factor (see subsequent discussion for ϕ).

83. For combined axial compression and moment the following procedure is used to evaluate the factor of safety at a cross section. The eccentricity corresponding to the applied loads M and P is $e = M/P$. The point corresponding to applied loads on the interaction diagram is illustrated in Figure 20. The load line (at eccentricity e) is extended to its intersection with the interaction curve to establish the nominal load capacity P_N at e for the section. The factor of safety is defined as

$$SF = \phi P_N/P \qquad \text{(VI-C.10)}$$

Strength Reduction Factor

84. If a nonzero value for ϕ is supplied as input, that value is

used throughout INVESTIGATION with SD. Otherwise, a value of ϕ for each cross section is calculated by the program as the minimum (but not less than 0.7) of

$$\phi = 0.9/[1 + 2P_N/(f'_c\ bh)] \qquad \text{(VI-C.11)}$$

or

$$\phi = 0.9 - 0.2\ P_N/P_B \qquad \text{(VI-C.12)}$$

PART VI-D: SHEAR INVESTIGATION

General

85. Shear factors of safety are calculated at two locations for each member as described below.

Allowable Shear Stress by ACI 63

86. Allowable shear stresses are determined at a distance d from each end of the clear span for all members. Allowable shear stresses v_{ca} are obtained from Equations (V-D.1) for WSD and Equations (V-D.2) for SD.

Allowable Shear Stress by U-of-I 440

87. Allowable shear stresses are calculated using Equation (V-D.3) at a distance $0.15\ell_n$ from each end of the clear span.

Shear Factors of Safety

88. The actual shear stress at each location is obtained from

$$v = V/bd$$

The shear factor of safety is given by

$$SF = v_{ca}/v$$

89. Shear factors of safety are not calculated:

a. If the shear force at a section is zero.

b. If axial tension force is present at the cross section.

c. By U-of-I 440 if ℓ_n/d [illegible] 11.5.

d. By ACI 63 if d [illegible] $0.15\ell_n$.

PART VII: COMPUTER PROGRAM

Program Description

90. The computer program, CORTCUL, which implements the procedures described above is written in FORTRAN for interactive execution from a remote terminal. All arithmetic operations are performed in single precision. For computer systems employing fewer than fifteen significant figures for real numbers it may be necessary to perform some operations in double precision.

Input Data

91. Input data may be provided interactively from the user terminal during execution or from a previously prepared data file. When data are input from the terminal during execution, prompting messages are provided to indicate the type and amount of data to be entered. The characteristics of a previously prepared data file are described in the Input Data Guide contained in Appendix A.

92. When the input sequence is complete, either from a data file or from the user terminal, the program offers the opportunity to change any or all parts of the input data in an EDIT mode.

93. Whenever any data are entered from the terminal, the existing data may be saved in input file format in a permanent file.

94. All input data are checked for consistency at the time of entry. However, more extensive checking for accuracy is performed on data entered from a data file. If it is desirable to enter data during execution from the user terminal, these data should be saved in a data file and the program should be restarted with input from the saved file. The program provides this option at the end of the input data sequence.

Output Data

95. Several options are available regarding the amount and destination of output from the program as described below.

Echoprint of Input Data

96. The echoprint contains a complete tabulation of all input read from the user terminal or from an input file, with control data calculated by the program and preset material properties. The user may direct this section of the output to the terminal, to an output file, to both, or the echoprint may be omitted entirely.

Design Results

97. Results generated in the DESIGN mode are presented in three parts:

a. DESIGN THICKNESSES: A tabulation of design thicknesses for roof, exterior walls, base, and interior walls with the governing stress condition (flexure or shear), the member which produced the required thickness, and the load case dictating the thickness. This section also contains the concrete area in the cross section.

b. DESIGN REINFORCEMENT AREAS: A tabulation of required reinforcement at each calculation point on each member. When multiple load cases require reinforcement in both faces of a member at a single location, two lines are printed for that location giving the maximum reinforcement required along with the load case, bending moment, and axial force controlling the reinforcement area.

c. DESIGN MEMBER LOAD/FORCE DATA: A tabulation of lateral load, bending moment, shear force, and axial force at each calculation point for each member for each load case.

Options for Design Results

98. All design results may be directed to the user terminal or to the output file containing the echoprint of input data. If the echoprint of input data was omitted or directed only to the terminal, an output file for results may be defined and the results may be directed to the

file, to the user terminal, or to both. Thicknesses and reinforcement data may not be omitted.

99. Member load/force data may be omitted entirely, or the data for any or all members may be selectively output.

Investigation Results

100. Results generated in the INVESTIGATION mode are separated into two parts.

a. SUMMARY OF RESULTS: A tabulation of bending moments and axial forces with material stresses for WSD or factors of safety for SD at the left end, centerline, and right end, and shear forces and factors of safety at each end of each member to be investigated for each load case. These results may be directed to either the user terminal or to an output file and may not be omitted.

b. MEMBER LOAD/FORCE RESULTS: A tabulation of lateral load, bending moment, shear, axial load (for special load cases), and axial force for each member to be investigated for each load case. These results may be omitted from the output or selectively output for any or all members.

Extent of Output

101. The number of printed lines of output depends on the options exercised for a particular problem. Following are estimates of the number of lines generated by each part of the output described above.

a. Echoprint of Input Data

100 + number of member load data lines for special load cases

b. DESIGN Thicknesses and Reinforcement Areas

40 + (NCELLS + 1)•WIDTH + (NCELLS/2 + 1)•RISE

c. Design Member Load/Force Data: For each member selected for output for each load case selected

10 + WIDTH for horizontal members

10 + RISE for vertical members

d. Summary of Results for INVESTIGATION

14 lines for each member investigated

e. Member Load/Force Results for INVESTIGATION

Same as for DESIGN Member Load/Force Data

102. When multicell culverts are DESIGNED or INVESTIGATED for multiple load cases, it is recommended that the output be saved in a permanent file and subsequently listed on a high speed printer.

PART VIII: EXAMPLE SOLUTIONS

General

103. Presented below are example solutions demonstrating the use of the program for both DESIGN and INVESTIGATION of orthogonal culverts. Output from the program and supporting information are presented in Appendix B.

Design of One Cell Culvert

104. The one cell culvert shown in Figure B-1 was designed for three situations. For the first case data were entered from the terminal during execution. Program prompts (upper case) and user response (lower case) are shown on pages B4 and B5. When all necessary input data have been provided, the program offers the opportunity for the user to edit the input data, to save data entered from the terminal in a permanent file, and to view an echoprint of the input data. In this case an echoprint only at the user terminal was requested. The echoprint is shown on pages B6 and B7. It should be noted that the echoprint also includes material properties (working stresses and moduli) calculated or preset by the program used during the design process. Appended to the echoprint is a schematic of the culvert with coordinate systems and sign conventions required for interpretation of output data, page B8. Subsequent to the echoprint, the user is offered the opportunity to continue or abort the solution of this problem. If the user elects to abort at this point, the program offers the opportunity to edit the input data just completed, to restart the program, or to terminate the run entirely. If the user elects to continue the solution, the program requests information regarding destionation of results; as indicated on page B8, results were printed at the terminal.

105. Following a repetition of the problem heading, DESIGN results, pages B9 through B11, consist of three parts: design thicknesses for the appropriate parts of the structure along with the load case, stress condition, and the member dictating the required thickness. Also provided is the gross concrete area in the structure cross section including

haunches. The second section of the DESIGN results presents the required reinforcement area and location of the reinforcement at each calculation point. (Note that locations of reinforcement are described as "TOP" or "BOT." Top and bottom for horizontal members are self-explanatory; top and bottom of vertical members are the left and right sides, respectively.) Reinforcement areas reported as "MIN" indicate that the plain concrete section is sufficient to carry the load at that point. These data are presented for the left half of the symmetrical system. The third part of the DESIGN results is a tabulation of loads and internal forces at the joints of the member and at the calculation points, page B11. These data are optional and may be output selectively for any or all members in the culvert or may be omitted.

106. After all output is complete, the user has the opportunity to revise the input data for the problem just completed, page B12. To illustrate the edit feature of the program, the input data for the one cell culvert design were altered, as shown on pages B12 and B13. Only the problem heading and the standard load case pressure coefficients were altered; all other data remain unchanged. An echoprint of the amended input data and the DESIGN results are shown on pages B14 through B18. As indicated on page B18, when output is complete, the input data may again be revised, the program may be restarted, or the run may be terminated. The notation "NORMAL TERMINATION" indicates that all files generated by the program have been placed in permanent status. Any intervention by the user or other abnormal termination prior to this message may result in loss of files generated by the program.

107. The culvert in each of the preceding examples was designed for a single load case. A working stress design of the one cell culvert for two load cases is illustrated on pages B19 through B27. In this case, input data were stored in a permanent file, listed on page B20, prior to execution. Program prompts and user responses are shown on page B19. For this problem all output data were directed to a permanent file which was subsequently listed after normal termination of the program. The echoprint of input data is given on pages B21 through B23 and DESIGN results are provided on pages B24 through B27. Significant differences in DESIGN results for multiple load cases occur in the tabulation of design

reinforcement data, pages B24 and B25. Load cases may produce reversal of bending at a single point, in which case tension reinforcement in each face of the member is required at that location. The maximum reinforcement required in each face at each point is presented. DESIGN load/force data were selectively output for both load cases and are given on pages B26 and B27.

108. It should be noted that the lateral load indicated on the base members of the culvert is the total reaction (soil and water, excluding base slab weight) calculated by the program.

Six Cell Culvert Design

109. The six cell culvert shown in Figure B2 was designed for two load cases by the ACI strength design procedure. Input data were stored in a permanent file, listed on page B31, prior to execution. Program prompts and user responses required to execute the program are shown on page B30.

110. The echoprint of input data is shown on pages B32 through B34. The necessary material property parameters for ACI strength design replace those previously noted for working stress design. The notation that the strength reduction factor (ϕ) is "VARIABLE" indicates that this factor is calculated by the program at each point in the structure. The notation that the reinforcement cover for interior walls is "CL" indicates that a single reinforcement area is to be considered at the centerline of these members.

111. DESIGN results are contained on pages B35 through B42. The results indicate that the design thickness of the interior walls was dictated by the minimum thickness for these walls supplied as input and not by the applied loads.

Three Cell Culvert Investigation

112. The three cell culvert shown in Figure B3 was investigated for two standard load cases using the ACI Strength Design Procedure. Input data were stored in a file, listed on page B46, prior to execution.

Program prompts and user responses required to execute the program are shown on page B45.

113. The echoprint of input data is shown on pages B47 through B49. As indicated in section 1.F of the echoprint, six members were selected for investigation. Because the structure and loading are symmetric, these six members are sufficient to indicate the response of the entire structure. Note also that no foundation reaction coefficients are provided, since the program determines the foundation reaction distribution from the applied loads (uniform in this case).

114. Output data, pages B50 through B54, consist of two parts. A summary of results, pages B50 through B53, provides the forces and attendant factors of safety for each member designated for investigation. Because the strength reduction factor was not specified as input, the strength reduction factor determined by the program is also printed. These data are output for each load case. It should be emphasized that the results for three locations may not coincide with a local *maximum* stress condition.

115. The summary of results may include one or more of the following messages:

a. "FACTOR OF SAFETY UNDEFINED DUE TO TENSION AXIAL FORCE OR ZERO TENSION REINFORCEMENT"
No attempt is made to calculate a flexure factor of safety under these conditions. Tension axial force may be produced by high internal water pressures or by unusual special load cases.

b. "FACTOR OF SAFETY = PHI * MN/M DUE TO ZERO AXIAL FORCE"
Ordinarily the factor of safety is calculated for the nominal axial load strength at actual eccentricity as indicated on page B50. If internal water pressures or special load cases result in zero axial load at a section, the factor of safety is based on pure bending strength.

c. "[illegible]"
This message is generated whenever [illegible].

116. The second part of output data consists of a tabulation of forces and loads associated with each member. These data are tabulated only for those members designated for investigation. [illegible]

data are optional and may be selected for any or all members investigated for any or all load cases, see page B45.

Four Cell Culvert Investigation

117. The four cell culvert shown in Figure B4 was investigated with the working stress design procedure. Loads were applied as a single special load case which includes concentrated loads on the roof and internal water in the third cell. Soil loads and the weight of the roof have been combined into the distributed roof load shown; weights of the vertical walls have been applied as distributed loads. Interactive entry of data from the terminal is depicted on page B57, and a listing of the predefined input data file is given on page B59. An echoprint of the input data is shown on pages B60 through B62. As indicated in part 1.F of the echoprint, eight members were selected for investigation.

118. The dimensions shown in Figure B4 indicate different covers for the interior of roof and end wall reinforcement. However, the program accepts only a single value of cover to describe both locations. For this illustration the cover for the interior roof reinforcement was used. To obtain a more accurate assessment of the factors of safety for the end walls, a second run using the end wall interior cover would be necessary. Note that cover dimensions do not affect internal forces calculated by the program.

119. Attention is directed to the reinforcement information provided for the interior vertical walls of the structure. Part 1.D indicates the reinforcement for these members is located on the member centerline. Consequently, it is necessary that both "TOP" and "BOTT[illegible] reinforcement areas be provided at each location for these memb[illegible] [illegible] the total reinforcement area, see data for member 14, part 1.F, page B61.

120. The output data again consist of two parts. The summary of results gives the internal forces and material stresses at the left and right ends and the centerline of the clear span and shear forces and factors of safety for each member designated for investigation. This information will be printed for each load case.

121. The summary of results may include the following messages:

a. "STRESS UNDEFINED DUE TO EXCESSIVE TENSION AXIAL FORCE OR NO TENSION REINFORCEMENT AT SECTION"

This message is generated whenever a tension axial force would result in tension stress in the concrete over the entire cross section or whenever zero reinforcement area occurs in the tension face of a member subjected to bending moment.

b. "NNNNNN-U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MESSAGE"

This message is generated whenever $\ell_n/d > 11.5$.

122. The second part of the output, pages B65 through B67, consists of a tabulation of loads and forces for each member designated for investigation. This section of the output is optional. These tabulations provide the foundation reaction necessary to equilibrate the unbalanced loads specified in the input data. Whenever a dual value of load and/or force occurs at a single location (i.e., sudden changes in shear due to concentrated lateral loads, see results for members 23 and 24) two lines for that location are printed giving the values immediately to the left and right, respectively, of the discontinuity.

REFERENCES

(1) Gamble, W. L. "Design of Thick Walled Multiple Opening Conduits to Resist Large Distributed Loads." Civil Engineering Studies, Structural Research Series No. 440, University of Illinois at Urbana-Champaign, Urbana, Illinois, April, 1977.

(2) "Building Code Requirements for Reinforced Concrete (ACI 318-63)." American Concrete Institute, Detroit, Michigan, 1963.

(3) "Building Code Requirements for Reinforced Concrete (ACI 318-77)." American Concrete Institute, Detroit, Michigan, 1977.

(4) Diaz de Cossio, R., and C. P. Siess, "Development of Design Criteria for Reinforced Concrete Box Culverts--Part II: Recommendations for Design." Civil Engineering Studies, Structural Research Series No. 164, University of Illinois, Urbana, Illinois, February, 1959.

(5) U.S. Corps of Engineers, "Conduits, Culverts and Pipes," EM 1110-2-2902, 3 March 1969.

APPENDIX A: INPUT GUIDE

Notes and General Requirements for Culvert Description

1. Culvert (see Figure 1)
   - a. The culvert is assumed to be composed of vertical and horizontal, straight, prismatic members.
   - b. A one foot slice perpendicular to the longitudinal axis of the culvert is analyzed.
   - c. The top slab has a constant thickness--T(1).
   - d. The end walls have the same thickness--T(2).
   - e. All interior walls have the same thickness--T(4).
   - f. The base slab has a constant thickness--T(3).
   - g. The height of all cell openings is the same--RISE.
   - h. Haunches are assumed to be at 45° with the axes of the members and, if used, are assumed to be the same size for all cells.
   - i. The culvert is assumed to be composed of 1 to 9 cells.
   - j. For DESIGN the cell width is assumed to be constant.
   - k. For INVESTIGATION the cell width may vary.
2. Elevations
   - a. Elevations are assumed to be in feet, decreasing downward.
   - b. The elevation of the culvert invert ELINV, Figure 1, is fixed.
3. Soil
   - a. The soil surrounding the culvert is assumed to be composed of one (1) to three (3) horizontal, homogeneous layers for DESIGN; or, zero (0) to three (3) layers for INVESTIGATION. (Note: Zero (0) soil layers indicate that all loads are applied by Special Load cases.)
   - b. The top elevation of the uppermost soil layer must be at or above the elevation of the invert.
   - c. The tops of other soil layers may be at any elevation.
   - d. The last soil layer described is assumed to extend ad infinitum downward.
   - e. Two (2) unit weights are required for each soil layer.
     - e(1) Moist Unit Weight, GAMMST, (PCF) is used if the soil is above groundwater elevation.
     - e(2) Saturated Unit Weight, GAMSAT, (PCF) is used to determine

the submerged unit weight ($\gamma_{submerged} = \gamma_{sat} - \gamma_w$) for soil below groundwater elevation.

4. Water--Two water effects are considered for each Standard Load case.
   a. Groundwater--Groundwater elevation, GWATEL, (Figure 1) may be at any elevation. Groundwater elevation influences the effective weight of the soil and hydrostatic pressures on the culvert.
   b. Internal Water--For INVESTIGATION water pressures may be imposed on the internal surfaces of any or all of the cells. Internal water pressures are determined from the effective water elevation specified for each cell. Internal water pressures are not permitted in the DESIGN mode.
5. Standard Loads
   a. Only loads due to soil, groundwater, surface surcharge, and structure weight are used for DESIGN.
   b. Nominal soil and surcharge loads are altered by vertical and horizontal pressure coefficients. One (1) to four (4) pairs of standard load coefficients (nonzero) with corresponding surcharge and groundwater elevation are required if Standard Loads are specified.
6. Special Loads
   a. Special Loads are permitted only for the INVESTIGATION mode.
   b. Up to four (4) Special Load cases are permitted. Each load case may contain up to eighty-four (84) lines of data describing the distribution of special loads.
7. Internal Water Loads
   a. Internal water loads are permitted only in the INVESTIGATION mode with Standard Loads. If internal water is present, its effects are combined with all Standard Load cases.
8. Load Factors
   a. If the SD method is specified, live (FLL) and dead (FDL) load factors (nonzero) must be provided.
   b. All Standard Loads except those due to structure weight are considered to be live loads.
   c. All Special Loads are considered to be live loads.

9. Reactions for Unbalanced Loads

a. For DESIGN, distribution of the base reaction is defined by two parameters, I and J (see Figure 8), viz:

I:J|QE:QCL

b. For INVESTIGATION, distribution of reactions for unbalanced loads is established by the program, see Figure 10.

10. Member Data for INVESTIGATION

a. In the INVESTIGATION mode, reinforcement areas are required for at least one (1) member.

11. Input Data

a. Input data may be entered during execution from the user's terminal or may be stored in a permanent file before the program is executed. The file name must be one (1) to six (6) alphanumeric characters beginning with an alphabetic character.

b. Data are read in free field format.

b(1) All data items must be separated by one or more blanks; comma separators are not allowed.

b(2) All variable names beginning with I, J, K, L, M, and N indicate integer values.

b(3) Integer number values must be of form NNNN.

b(4) Real number values may be of form XXXX, XX.XX, X.XXE+ee.

c. Each line in a data file must begin with a nonzero integer line number denoted LN below. Line numbers are not required when data are entered during execution from the user's terminal.

d. Input data lines must be in the sequence described below. Line descriptors enclosed in brackets [ ] or braces { } may not be required.

e. Lower case words enclosed by single quotes in the description below indicate alphanumeric information.

f. All alphanumeric keywords may be abbreviated with the underlined character(s).

12. Input Data Sequence and Description

a. Header--One (1) to four (4) lines are provided for identifying the run.

a(1) Header Line 1

(a) Contents

[LN] NLINES 'heading'

(b) Definitions

[LN] = line number (not required if data entered during execution from user's terminal)

NLINES = total number of header lines = integer 1 to 4

'header' = any alphanumeric information

(c) Total characters on Header Line 1 including LN, NLINES, 'heading,' and embedded blanks must be ≤ 80. Blank 'heading' is not permitted.

a(2) Header Lines 2 to NLINES ([data] not required if NLINES = 1)

(a) Contents

[LN] ['heading']

(b) Total characters including LN, 'heading,' and embedded blanks must be ≤ 80. Blank 'heading' is not permitted.

b. Mode, Method--One (1) line (alphanumeric)

b(1) Contents

[LN] 'mode' 'method' [SHROPT]

b(2) Definitions

'mode' = DESIGN OR INVESTIGATION

'method' = WSD or SD

SHROPT = Design Shear Option (see paragraph 64, page 48)
= 1, 2, or 3 if 'Mode' = DESIGN and 'Method' = WSD;
= 1 or 2 if 'Mode' = DESIGN and 'Method' = SD;
Omit if 'Mode' = INVESTIGATION

c. Material Properties and Design Factors--One (1) line (numeric)

c(1) Contents

[LN] FC FY WTCONC [RMAX PHI]

c(2) Definitions

FC = ultimate concrete strength (PSI)

FY = reinforcement yield strength (PSI)

WTCONC = concrete unit weight (PCF)

RMAX = maximum steel ratio ($0 < RMAX < 1$) (A_s/A_{sb}); omit if 'method' = WSD

PHI = strength reduction factor ($0 \le PHI < 1$); omit if 'method' = WSD; if input = zero, calculated by program for 'method' = SD.

d. Culvert Geometry--One (1) or two (2) lines

d(1) Control--One (1) line

(a) Contents

[LN] NCELLS RISE HAUNCH ELINV WIDTH

(b) Definitions

NCELLS = number of cells (1 to 9)

RISE = height of cell opening (FT)

HAUNCH = haunch width (IN.)

ELINV = elevation of invert (FT)

WIDTH:
- For DESIGN = width of cell openings (FT)
- For INVESTIGATION, if > 0 = width of all cell openings (FT)
- For INVESTIGATION, if = 0, width of cell openings varies as given in line 2 below

d(2) Cell Widths--One (1) line if 'mode' = INVESTIGATION and WIDTH = 0 above; omit if 'mode' = DESIGN

(a) Contents

[LN] [WIDTH(1) WIDTH(2) . . . WIDTH(NCELLS)]

(b) Definition

WIDTH(I) = width of Ith cell opening (FT)

e. Reinforcement Cover--One (1) line

e(1) Contents

[LN] COVER(1) COVER(2) COVER(3) [COVER(4)]

e(2) Definitions

COVER(1) = distance (IN.) from centroid of reinforcement to exterior surface of all exterior members

COVER(2) = distance (IN.) from centroid of reinforcement to interior surface of roof and exterior walls

COVER(3) = distance (IN.) from centroid of reinforcement to interior face of base

COVER(4) = distance (IN.) from centroid of reinforcement to tension face for all interior walls; omit if NCELLS = 1; reinforcement assumed at middle of member if input equal to zero

f. Member Thicknesses--One (1) line

f(1) Contents

[LN] T(1) T(2) T(3) [T(4)]

f(2) Definitions

T(1) = thickness (IN.) of roof

T(2) = thickness (IN.) of exterior walls

T(3) = thickness (IN.) of base

T(4) = thickness (IN.) of interior walls; omit if NCELLS = 1

Thicknesses are minimum acceptable thickness if 'mode' = DESIGN

Thicknesses are actual thicknesses if 'mode' = INVESTIGATION

g. Maximum Reinforcement Areas--One (1) line if 'mode' = DESIGN; omit if 'mode' = INVESTIGATION

g(1) Contents

[LN ASMAX(1) ASMAX(2) ASMAX(3) {ASMAX(4)}]

g(2) Definitions

ASMAX(1) = maximum permissible reinforcement area for roof ($IN.^2$)

ASMAX(2) = maximum area for exterior walls ($IN.^2$)

ASMAX(3) = maximum area for base ($IN.^2$)

ASMAX(4) = maximum area for interior walls ($IN.^2$); omit if NCELLS = 1

h. Soil Data--One (1) to four (4) lines

h(1) Control--One line

(a) Contents

[LN] NLAYER

(b) Definition

NLAYER = number of soil layers; one (1) to three (3) if 'mode' = DESIGN; zero (0) to three (3) if 'mode' = INVESTIGATION

h(2) Soil Layer Data--NLAYER lines (Layer 1 is surface layer, layers proceed sequentially downward); omit if NLAYER = 0

(a) Contents

{[LN] ELLAY(I) GAMSAT(I) GAMMST(I)}

(b) Definitions

ELLAY(I) = elevation at top of layer (FT)

GAMSAT(I) = saturated unit weight of layer (PCF)

GAMMST(I) = moist (submerged) unit weight of layer (PCF)

i. Standard Load Case Data--Zero (0) to five (5) lines; omit entire section if NLAYER = 0

i(1) Control--One (1) line

(a) Contents

{[LN] NSTCAS [GAMWAT]}

(b) Definitions

NSTCAS = number of Standard Load cases (1 to 4)

GAMWAT = unit weight of water (PCF); set to 62.5 if input as zero or omitted

i(2) Standard Load Case Coefficients--NSTCAS line

(a) Contents

{[LN] VCOEFF(I) HCOEFF(I)} {[SURCH(I) GWATEL(I)]}

(b) Definitions

VCOEFF(I)* = coefficient for vertical soil pressures

HCOEFF(I)* = coefficient for horizontal soil pressures

SURCH(I)** = surface surcharge (PSF) for Load Case I

GWATEL(I)** = groundwater elevation (FT) for Load Case I

*Coefficient for horizontal pressure due to surcharge HCOEFF(I) : VCOEFF(I)

**If both SURCH(I) and GWATEL(I) are omitted, surcharge and groundwater effects are ignored.

j. Special Load Data--One (1) to three hundred forty (340) lines; omit entire section if 'mode' = DESIGN

j(1) Control--One (1) line

(a) Contents

{[LN] NSPCAS}

(b) Definition

NSPCAS = number of Special Load cases (0 to 4)

j(2) Special Load Case Data--Two (2) to eighty-five (85) lines; omit if NSPCAS = 0

(a) Control--One (1) line

(a1) Contents

{[LN] NLDMEM(N)}

(a2) Definition

NLDMEM(N) = number of member load lines in Special Load case N (1 to 84)

(b) Member Load Lines--NLDMEM(N) lines

(b1) Contents

{[LN] LDMEM(N,I), LDDIR(N,I), LDTYPE(N,I), Q(N,I), DIST(N,I,1), [DIST(N,I,2)], [IEND(N,1)]}

(b2) Definitions

LDMEM(N,I) = member number

LDDIR(N,I) = load direction in member coordinate system = X or Y

LDTYPE(N,I) = Load type
= C for concentrated load
= U for uniform load
= T for triangular load

Q(N,1) = load magnitude for concentrated load (PLF)
= load magnitude for uniform load (PSF)
= maximum load magnitude for triangular load (PSF)

DIST(N,I,I) = distance from member coordinate origin to concentrated load or to start or distributed load (FT)

DIST(N,I,2) = distance to end of distributed load (FT); omit if LDTYPE(N,I) = C

IEND(N,I,1) = indicator for triangular load; omit for other load types
= L if maximum occurs at left (start) end
= R if maximum occurs at right end

j(3) Repeat section j(2) NSPCAS times

k. Load Factors--One line if 'method' = SD; omit if 'method' = WSD

k(1) Contents

{[LN] FLL FDL}

k(2) Definitions

FLL = live load factor (> 0)

FDL = dead load factor (> 0)

l. Base Reaction Distribution Indicators--One (1) line if 'mode' = DESIGN; omit if 'mode' = INVESTIGATION

l(1) Contents

{[LN] XI XJ}

l(2) Definitions

XI, XJ indicate relative values of edge and centerline base reactions

XI:XJ|QE:QCL

m. Internal Water Data--One (1) or two (2) lines; omit entire section if 'mode' = DESIGN or if NSTCAS = 0

m(1) Control--One (1) line

(a) Contents

[LN] IWAT

(b) Definitions

IWAT = indicator for internal water

= 0, no internal water

= 1, internal water elevations specified

m(2) Internal Water Elevations--Zero (0) or one (1) line; omit if 'mode' = DESIGN, if IWAT = 0, or if NSTCAS = 0

(a) Contents

{[LN] CELWAT(1) CELWAT(2) . . . CELWAT(NCELLS)}

(b) Definition

CELWAT(I) = effective elevation (FT) of internal water in cell I; if less than ELINV, no internal water in cell I

n. Member Data for INVESTIGATION--Zero (0) or two (2) to twenty-nine (29) lines; omit entire section if 'mode' = DESIGN

n(1) Control--One (1) line

(a) Contents

{[LN] NMINV}

(b) Definition

NMINV = number of members to be investigated (1 to total number of members in culvert)

n(2) Member Data--NMINV lines

(a) Contents

{[LN] INVMEM(N) ASTL(N) ASBL(N) ASTC(N) ASBC(N) ASTR(N) ASBR(N)}

(b) Definitions

INVMEM(N) = member number

ASTL( ), ASTC( ), ASTR( ) = area (in.^{2}) of steel in "TOP" of member at left end, centerline, and right end, respectively

ASBL( ), ASBC( ), ASBR( ) = area (in.^{2}) of steel in "BOTTOM" of member at left end, centerline, and right end, respectively

Abbreviated Input Guide

1. Notation

   a. Data items enclosed in brackets [ ] may not be required

   b. Data items enclosed in braces { } indicate choose one

2. Input

   a. Header--One (1) to four (4) lines

      LN NLINES 'heading'

      [LN 'heading']

      [LN 'heading']

      [LN 'heading']

   b. Mode, Method, Procedure--One (1) line

      $$\text{LN} \quad \left\{\begin{array}{l}\text{DESIGN}\\ \text{INVESTIGATION}\end{array}\right\} \quad \left\{\begin{array}{l}\text{WSD}\\ \text{SD}\end{array}\right\} \quad [\text{[illegible]}]$$

   c. Material Properties and Design Factors--One (1) line

      LN FC FY WTCONC [RMAX PHI]

   d. Culvert Geometry--One (1) or two (2) lines

      d(1) Control--One (1) line

         LN NCELLS RISE HAUNCH ELINV WIDTH

      d(2) Cell Widths--Zero (0) or one (1) line

         [LN WIDTH(1) WIDTH(2) . . . WIDTH(NCELLS)]

   e. Reinforcement Cover--One (1) line

      LN COVER(1) COVER(2) COVER(3) [COVER(4)]

   f. Member Thicknesses--One (1) line

      LN T(1) T(2) T(3) [T(4)]

   g. Maximum Reinforcement Areas--Zero (0) or one (1) line

      [LN ASMAX(1) ASMAX(2) ASMAX(3) [ASMAX(4)]]

   h. Soil Data--One (1) to four (4) lines

      h(1) Control--One (1) line

         LN NLAYER

      h(2) Soil Layer Data--NLAYER lines

         [LN ELLAY(I) GAMSAT(I) GAMMST(I)]

   i. Standard Load Case Data--Omit entire section if NLAYER = 0; otherwise two (2) to five (5) lines

      i(1) Control--One (1) line

         [LN NSTCAS GAMWAT]

i(2) Standard Load Case Coefficients--One (1) to four (4) lines

[LN VCOEFF(I) HCOEFF(I) SURCH(I) GWATEL(I)]

j. Special Load Data--Omit entire section if 'mode' = DESIGN; otherwise one (1) to three hundred forty (340) lines

j(1) Control--One (1) line

[LN NSPCAS]

j(2) Special Load Case Data--Two (2) to eighty-five (85) lines

(a) Control--One (1) line

[LN NLDMEM(N)]

(b) Member Load Lines--One (1) to eighty-four (84) lines

$$[\text{LN}\quad \text{LDMEM(N,I)}\quad \begin{Bmatrix} \text{X} \\ \text{Y} \end{Bmatrix}\quad \begin{Bmatrix} \text{C} \\ \text{U} \\ \text{T} \end{Bmatrix}\quad \text{Q(N,I)},$$

$$\text{DIST(N,I,1)}\quad [\text{DIST(N,I,2)}]\quad [\text{IEND(N,I)}]]$$

j(3) Repeat section j(2) NSPCAS times

k. Load Factors--One (1) line if 'method' = USD; omit if 'method' = WSD

[LN FLL FDL]

l. Base Reaction Distribution Indicators--One (1) line if 'mode' = DESIGN, otherwise omit

[LN XI XJ]

m. Water Data--One (1) or two (2) lines if 'mode' = INVESTIGATION and NSTCAS > 0; otherwise omit

m(1) Control--One (1) line

[LN IWAT]

m(2) Internal Water Elevations--Zero (0) or one (1) line

[LN CELWAT(1) CELWAT(2) . . . CELWAT(NCELLS)]

n. Member Data for INVESTIGATION--Zero (0) or two (2) to twenty-nine (29) lines

n(1) Control--One (1) line

[LN NMINV]

n(2) Member Data--NMINV lines

[LN INVMEM(N) ASTL(N) ASBL(N) ASTR(N) ASBR(N)
ASTE(N) ASBE(N)]

APPENDIX B: SOLUTIONS

ONE CELL CULVERT DESIGN

BY WORKING STRESS DESIGN PROCEDURE

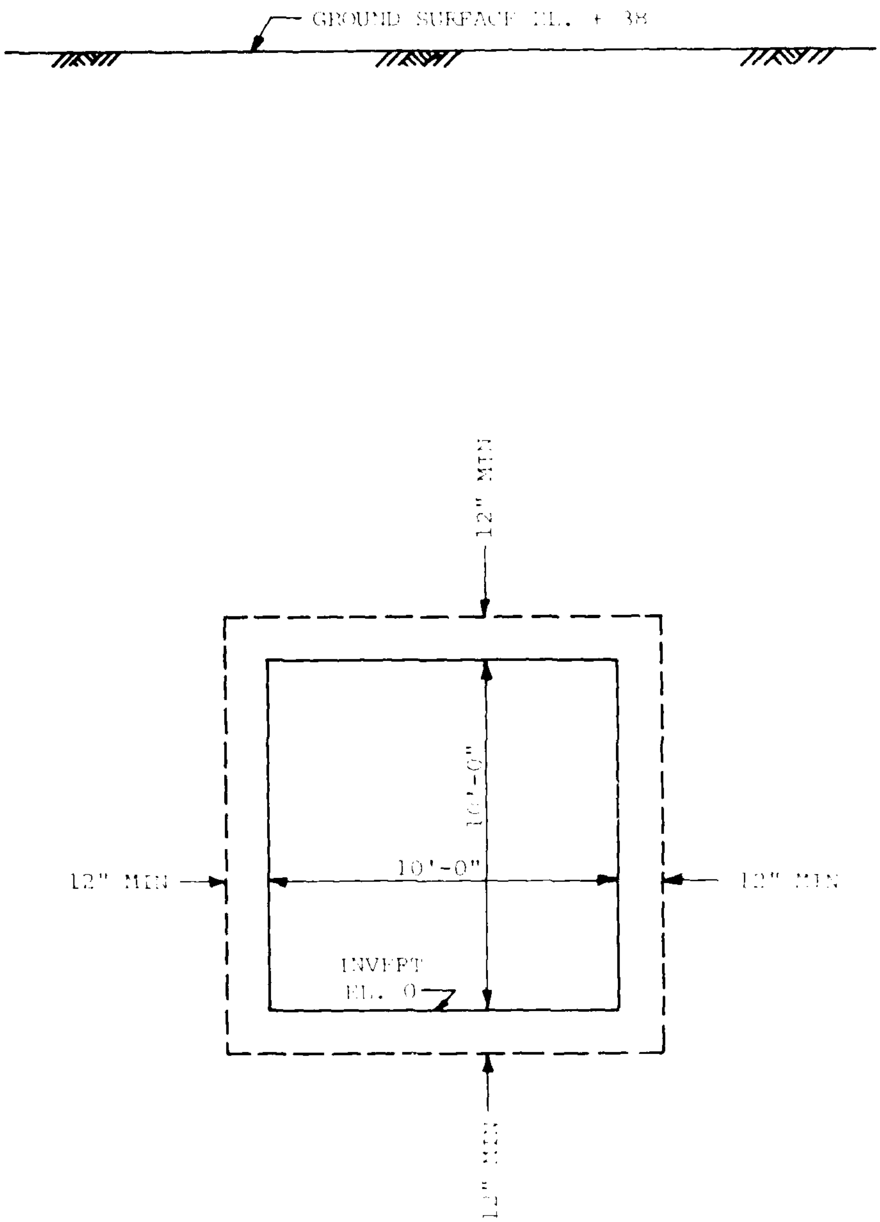


Figure B1. System for one-cell culvert design

AD-A100 968 DAWKINS (WILLIAM P) STILLWATER OK F/G 13/13
USER'S GUIDE: COMPUTER PROGRAM FOR DESIGN OR INVESTIGATION OF O--ETC(U)
MAR 81 W P DAWKINS DACW39-80-M-0334
UNCLASSIFIED WES-INSTRUCTION-K-81-7 NL

2 OF 3
AD A
100968

```
     PROGRAM  CORTCUL  DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
     DATE: 08/22/80                                    TIME: 06:49:14


     ARE INPUT DATA TO BE READ FROM TERMINAL OR FILE?
     ENTER 'TERMINAL' OR 'FILE'
I>t


     ENTER NUMBER OF HEADER LINES (1 TO 4)
I>4
     ENTER HEADER LINE 1 (72 CHARACTERS MAXIMUM)
I>design of one cell culvert
     ENTER HEADER LINE 2 (72 CHARACTERS MAXIMUM)
I>working stress design procedure
     ENTER HEADER LINE 3 (72 CHARACTERS MAXIMUM)
I>shear design with combination of ui440 and aci63
     ENTER HEADER LINE 4 (72 CHARACTERS MAXIMUM)
I>one load case -- 1 to 1 loading
     MODE?  ENTER 'DESIGN' OR 'INVESTIGATION'
I>d
     METHOD? ENTER 'WSD' OR 'SD'
I>wsd
     SHEAR DESIGN OPTION? ENTER 1, 2 OR 3
I>2
     MATERIAL PROPERTIES, ENTER VALUES UNDER HEADINGS
               CONCRETE        REINF      CONCRETE
              COMPRESSIVE      YIELD        UNIT
               STRENGTH      STRENGTH     WEIGHT
                 (PSI)         (PSI)       (PCF)
I>4000 40000 150
     GEOMETRY DATA
          NO OF       CELL      HAUNCH    INVERT      CELL
          CELLS      HEIGHT     WIDTH      ELEV      WIDTH
         (1 TO 9)     (FT)       (IN)      (FT)       (FT)
I>1 10 0 0 10
     COVER TO CENTROID OF REINFORCEMENT
          EXTERIOR           INTERIOR SURFACES
          SURFACES      ROOF/EXT.WALLS     BASE SLAB
            (IN)             (IN)             (IN)
I>4 4 4
     MINIMUM ALLOWABLE THICKNESSES
              ROOF       EXTERIOR      BASE
              SLAB         WALLS       SLAB
              (IN)         (IN)        (IN)
I>12 12 12
     MAXIMUM PERMISSIBLE REINFORCEMENT AREAS
              ROOF       EXTERIOR      BASE
              SLAB         WALLS       SLAB
             (SQIN)       (SQIN)      (SQIN)
I>2 2 2
```

```
     STANDARD LOAD DATA. ENTER NUMBER OF SOIL LAYERS (1 TO 3)
I>1
     SOIL LAYER DATA. ENTER ONE LINE PER LAYER
           ELEV AT            UNIT WEIGHTS
          LAYER TOP       SATURATED       MOIST
            (FT)            (PCF)         (PCF)
I>38 125 125
     ENTER NUMBER OF STANDARD LOAD CASES (1 TO 4)
I>1
     ENTER GROUND WATER UNIT WEIGHT (PCF)
I>62.5
     ENTER 1 LINES OF STANDARD LOAD CASE DATA.  ONE LINE AT A TIME.

           PRESSURE COEFFICIENTS       SURFACE      GROUND WATER
           VERTICAL   HORIZONTAL      SURCHARGE       ELEVATION
                                        (PSF)           (FT)
I>1 1 0 -1000
     ENTER FOUNDATION REACTION DISTRIBUTION COEFFICIENTS
          I     J
I>1 1
     INPUT COMPLETE. NO ERRORS DETECTED.
     DO YOU WANT TO EDIT INPUT DATA? ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA SAVED IN A FILE? ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA ECHOPRINTED TO YOUR
     TERMINAL, TO A FILE, TO BOTH, OR NEITHER?
     ENTER 'TERMINAL', 'FILE', 'BOTH', OR 'NEITHER'
I>t
```

```
PROGRAM  CORTCUL  DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80                                 TIME: 06:55:09

1. INPUT DATA

1.A.--HEADING

DESIGN OF ONE CELL CULVERT
WORKING STRESS DESIGN PROCEDURE
SHEAR DESIGN WITH COMBINATION OF UI440 AND ACI63
ONE LOAD CASE -- 1 TO 1 LOADING


1.B.--MODE AND PROCEDURE
     DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
     SHEAR DESIGN OPTION 2


1.C.--MATERIAL PROPERTIES

     CONCRETE:
          ULTIMATE STRENGTH      =  4000.       (PSI)
          WORKING STRESS         =  1800.       (PSI)
          MODULUS OF ELASTICITY  =     3.8E+06  (PSI)
          UNIT WEIGHT            =   150.       (PCF)


     REINFORCEMENT:
          YIELD STRENGTH         = 40000.       (PSI)
          WORKING STRESS         = 20000.       (PSI)
          MODULUS OF ELASTICITY  =    29.E+06   (PSI)


     MODULAR RATIO (ES/EC)       =      7.563


1.D.--GEOMETRY
     NO OF       CELL      HAUNCH       INVERT       CELL
     CELLS      HEIGHT      WIDTH        ELEV        WIDTH
                 (FT)       (IN)         (FT)         (FT)
       1         10.00       0.00         0.00        10.00


     REINFORCEMENT COVER (IN):          MINIMUM THICKNESS (IN):
     EXTERIOR SURFACES       = 4.00     ROOF SLAB       = 12.00
     INTERIOR ROOF/END WALLS = 4.00     EXTERIOR WALLS = 12.00
     INTERIOR BASE SLAB      = 4.00     BASE SLAB       = 12.00


     MAXIMUM REINF AREA  (SQIN):
     ROOF SLAB      = 2.00
     EXTERIOR WALLS = 2.00
     BASE SLAB      = 2.00
```

1.E.--LOAD DATA

1.E.1.--STANDARD LOAD CASES

SOIL DATA:

LAYER NO	ELEV AT TOP OF LAYER (FT)	SATURATED UNIT WEIGHT (PCF)	MOIST UNIT WEIGHT (PCF)
1	38.00	125.00	125.00

STANDARD LOAD CASE DATA
WATER UNIT WEIGHT = 62.5 (PCF)

LOAD CASE	PRESSURE COEFFICIENTS VERTICAL	PRESSURE COEFFICIENTS HORIZONTAL	SURFACE SURCHARGE (PSF)	GROUND WATER ELEVATION (FT)
1	1.00	1.00	0.00	-1000.00

FOUNDATION REACTION COEFFICIENTS:
OUTER EDGES = 1.00
CENTERLINE = 1.00

1.E.2--SPECIAL LOAD CASES

NO SPECIAL LOAD CASES

1.E.4--INTERNAL WATER DATA

NO INTERNAL WATER

```
                    SCHEMATIC OF CULVERT:

                          *--21--*
                          !      !
                          !      !
                         11      12
                          !      !
                          !      !
                          *---1--*


LOCAL COORDINATE SYSTEMS:
     HORIZONTAL MEMBERS: ORIGIN AT LEFT END, X-AXIS TO RIGHT, Y-AXIS UP
     VERTICAL MEMBERS  : ORIGIN AT BOTTOM, X-AXIS UP, Y-AXIS TO LEFT

SIGN CONVENTIONS:
     POSITIVE LATERAL LOAD ACTS IN PLUS Y DIRECTION
     POSITIVE BENDING MOMENT PRODUCES COMPRESSION
          ON PLUS Y FACE OF MEMBER
     POSITIVE SHEAR TENDS TO MOVE MEMBER IN PLUS Y DIRECTION
     POSITIVE AXIAL LOAD ACTS IN PLUS X DIRECTION
     POSITIVE AXIAL INTERNAL FORCE IS COMPRESSION




INPUT SEQUENCE COMPLETE.
DO YOU WANT TO CONTINUE SOLUTION?  ENTER 'YES' OR 'NO'
I>y
DO YOU WANT RESULTS PRINTED AT YOUR TERMINAL,
WRITTEN TO A FILE, OR BOTH?
ENTER 'TERMINAL', 'FILE', OR 'BOTH'
I>t
SOLUTION COMPLETE
```

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 06:55:29

2.--DESIGN RESULTS

2.A.--HEADING

DESIGN OF ONE CELL CULVERT
WORKING STRESS DESIGN PROCEDURE
SHEAR DESIGN WITH COMBINATION OF UI440 AND ACI63
ONE LOAD CASE -- 1 TO 1 LOADING

2.B.--DESIGN THICKNESSES
DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

	DESIGN THICKNESS (IN)	<------CONTROLLING------> LOAD CASE	STRESS CONDITION	MEMBER
ROOF SLAB :	18.	1	SHEAR	21
EXTERIOR WALLS:	18.	1	SHEAR	11
BASE SLAB :	18.	1	SHEAR	1

CONCRETE AREA IN CROSS SECTION = 69.00 (SQFT)

2.C.--DESIGN REINFORCEMENT DATA FOR LEFT HALF OF SYSTEM
DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

MEMBER NUMBER 1

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.75	1	32.07	29.12	BOT	.69
3.25	1	-4.33	29.12	TOP	MIN
5.75	1	-16.47	29.12	TOP	MIN
8.25	1	-4.33	29.12	TOP	MIN
10.75	1	32.07	29.12	BOT	.69

MEMBER NUMBER 11

DIST FROM LEFT END (FT)	LOAD CASE	<------CONTROLLING------> BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.75	1	-30.28	25.08	TOP	.72
3.25	1	9.84	24.51	BOT	MIN
5.75	1	22.23	23.95	BOT	.34
8.25	1	8.84	23.39	BOT	MIN
10.75	1	-28.38	22.83	TOP	.68

MEMBER NUMBER 21

DIST FROM LEFT END (FT)	LOAD CASE	<------CONTROLLING------> BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.75	1	-29.70	24.50	TOP	.70
3.25	1	3.47	24.50	BOT	MIN
5.75	1	14.52	24.50	BOT	MIN
8.25	1	3.47	24.50	BOT	MIN
10.75	1	-29.70	24.50	TOP	.70

```
    DO YOU WANT DESIGN MEMBER LOAD/FORCE DATA OUTPUT?
I>y
    WHICH MEMBER LOAD/FORCE DATA ARE DESIRED FOR LOAD CASE 1?
    ENTER LIST OR RANGE OF MEMBER NUMBERS, OR 'ALL', OR 'NONE', OR 'HELP'
I>a
```

3.--DESIGN MEMBER LOAD/FORCE DATA, LOAD CASE 1
DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

DESIGN LOAD/FORCE DATA FOR MEMBER 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	3.88	47.73	-22.33	29.12
.75	3.88	32.07	-19.42	29.12
3.25	3.88	-4.33	-9.71	29.12
5.75	3.88	-16.47	-.00	29.12
8.25	3.88	-4.33	9.71	29.12
10.75	3.88	32.07	19.42	29.12
11.50	3.88	47.73	22.33	29.12

DESIGN LOAD/FORCE DATA FOR MEMBER 11

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-4.84	-48.02	25.45	25.24
.75	-4.75	-30.28	21.86	25.08
3.25	-4.44	9.84	10.37	24.51
5.75	-4.13	22.23	-.33	23.95
8.25	-3.81	8.84	-10.25	23.39
10.75	-3.50	-28.38	-19.39	22.83
11.50	-3.41	-43.90	-21.98	22.66

DESIGN LOAD/FORCE DATA FOR MEMBER 12

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	4.84	48.02	-25.45	25.24
.75	4.75	30.28	-21.86	25.08
3.25	4.44	-9.84	-10.37	24.51
5.75	4.13	-22.23	.33	23.95
8.25	3.81	-8.84	10.25	23.39
10.75	3.50	28.38	19.39	22.83
11.50	3.41	43.90	21.98	22.66

DESIGN LOAD/FORCE DATA FOR MEMBER 21

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-3.54	-43.96	20.34	24.50
.75	-3.54	-29.70	17.69	24.50
3.25	-3.54	3.47	8.84	24.50
5.75	-3.54	14.52	.00	24.50
8.25	-3.54	3.47	-8.84	24.50
10.75	-3.54	-29.70	-17.69	24.50
11.50	-3.54	-43.96	-20.34	24.50

OUTPUT COMPLETE.
DO YOU WANT TO EDIT INPUT DATA FOR THE PRECEDING PROBLEM?
ENTER 'YES' OR 'NO'
I>N

```
     DO YOU WANT A LISTING OF CURRENT INPUT DATA?
     ENTER 'YES' OR 'NO'
I>n

     FOLLOWING ARE IDENTIFIERS FOR SECTIONS OF INPUT DATA
          SECTION ID      SECTION CONTENTS
               A...........HEADING
               B...........MODE, METHOD
               C...........MATERIAL PROPERTIES
               D...........GEOMETRY
               E...........LOAD DATA
               F...........INTERNAL WATER DATA
               G...........MEMBER DATA FOR INVESTIGATION

     ENTER ID FOR DATA SECTION TO BE CHANGED
     OR 'NONE' IF NO SECTION TO BE CHANGED
I>a

     ENTER NUMBER OF HEADER LINES (1 TO 4)
I>4
     ENTER HEADER LINE 1 (72 CHARACTERS MAXIMUM)
I>design of one cell culvert
     ENTER HEADER LINE 2 (72 CHARACTERS MAXIMUM)
I>working stress design procedure
     ENTER HEADER LINE 3 (72 CHARACTERS MAXIMUM)
I>shear design with combination of ui440 and aci63
     ENTER HEADER LINE 4 (72 CHARACTERS MAXIMUM)
I>one load case -- 1.5 to .5 loading

     DO YOU WANT TO CHANGE ANOTHER SECTION?
     ENTER 'YES' OR 'NO'
I>y

     ENTER ID FOR DATA SECTION TO BE CHANGED
     OR 'NONE' IF NO SECTION TO BE CHANGED
I>e
```

```
     FOLLOWING PARTS OF LOAD DATA
     MAY BE CHANGED INDIVIDUALLY:
               PART NO     CONTENTS
                  1...........SOIL DATA
                  2...........STANDARD LOAD CASE DATA
                  3...........FOUNDATION REACTION COEFFICIENTS
                  4...........LOAD FACTORS FOR ACI STRENGTH DESIGN METHOD
                  5...........SPECIAL LOAD CASE DATA

     ENTER PART NUMBER FOR PART TO BE CHANGED
     OR 'ALL' TO CHANGE ENTIRE SECTION
     OR 'NONE' IF NO PART TO BE CHANGED
I>2
     ENTER NUMBER OF STANDARD LOAD CASES (1 TO 4)
I>1
     ENTER GROUND WATER UNIT WEIGHT (PCF)
I>62.5
     ENTER 1 LINES OF STANDARD LOAD CASE DATA.  ONE LINE AT A TIME.

           PRESSURE COEFFICIENTS       SURFACE       GROUND WATER
           VERTICAL   HORIZONTAL       SURCHARGE       ELEVATION
                                         (PSF)           (FT)
I>1.5 .5 0 -1000

     DO YOU WANT TO CHANGE ANOTHER PART OF
     LOAD DATA? ENTER 'YES' OR 'NO'
I>n

     DO YOU WANT TO CHANGE ANOTHER SECTION?
     ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA SAVED IN A FILE? ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA ECHOPRINTED TO YOUR
     TERMINAL, TO A FILE, TO BOTH, OR NEITHER?
     ENTER 'TERMINAL', 'FILE', 'BOTH', OR 'NEITHER'
I>t
```

```
PROGRAM CORTCUL DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80                                  TIME: 07:00:18

1. INPUT DATA

1.A.--HEADING

DESIGN OF ONE CELL CULVERT
WORKING STRESS DESIGN PROCEDURE
SHEAR DESIGN WITH COMBINATION OF UI440 AND ACI63
ONE LOAD CASE -- 1.5 TO .5 LOADING


1.B.--MODE AND PROCEDURE
     DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
     SHEAR DESIGN OPTION 2


1.C.--MATERIAL PROPERTIES

     CONCRETE:
          ULTIMATE STRENGTH      =  4000.       (PSI)
          WORKING STRESS         =  1800.       (PSI)
          MODULUS OF ELASTICITY  =     3.8E+06  (PSI)
          UNIT WEIGHT            =   150.       (PCF)


     REINFORCEMENT:
          YIELD STRENGTH         = 40000.       (PSI)
          WORKING STRESS         = 20000.       (PSI)
          MODULUS OF ELASTICITY  =    29.E+06   (PSI)


     MODULAR RATIO (ES/EC)       =      7.563


1.D.--GEOMETRY
     NO OF       CELL      HAUNCH       INVERT      CELL
     CELLS      HEIGHT      WIDTH        ELEV       WIDTH
                 (FT)       (IN)         (FT)        (FT)
       1        10.00       0.00         0.00       10.00


     REINFORCEMENT COVER (IN):           MINIMUM THICKNESS (IN):
     EXTERIOR SURFACES       = 4.00      ROOF SLAB       = 12.00
     INTERIOR ROOF/END WALLS = 4.00      EXTERIOR WALLS  = 12.00
     INTERIOR BASE SLAB      = 4.00      BASE SLAB       = 12.00


     MAXIMUM REINF AREA  (SQIN):
     ROOF SLAB      = 2.00
     EXTERIOR WALLS = 2.00
     BASE SLAB      = 2.00
```

1.E.--LOAD DATA

1.E.1.--STANDARD LOAD CASES

SOIL DATA:

LAYER NO	ELEV AT TOP OF LAYER (FT)	SATURATED UNIT WEIGHT (PCF)	MOIST UNIT WEIGHT (PCF)
1	38.00	125.00	125.00

STANDARD LOAD CASE DATA
WATER UNIT WEIGHT = 62.5 (PCF)

LOAD CASE	PRESSURE COEFFICIENTS VERTICAL	PRESSURE COEFFICIENTS HORIZONTAL	SURFACE SURCHARGE (PSF)	GROUND WATER ELEVATION (FT)
1	1.50	.50	0.00	-1000.00

FOUNDATION REACTION COEFFICIENTS:
OUTER EDGES = 1.00
CENTERLINE = 1.00

1.E.2--SPECIAL LOAD CASES
NO SPECIAL LOAD CASES

1.E.4--INTERNAL WATER DATA
NO INTERNAL WATER

```
                    SCHEMATIC OF CULVERT:

                         *--21--*
                         !      !
                         !      !
                        11      12
                         !      !
                         !      !
                         *---1--*


     LOCAL COORDINATE SYSTEMS:
          HORIZONTAL MEMBERS: ORIGIN AT LEFT END, X-AXIS TO RIGHT, Y-AXIS UP
          VERTICAL MEMBERS  : ORIGIN AT BOTTOM, X-AXIS UP, Y-AXIS TO LEFT

     SIGN CONVENTIONS:
          POSITIVE LATERAL LOAD ACTS IN PLUS Y DIRECTION
          POSITIVE BENDING MOMENT PRODUCES COMPRESSION
               ON PLUS Y FACE OF MEMBER
          POSITIVE SHEAR TENDS TO MOVE MEMBER IN PLUS Y DIRECTION
          POSITIVE AXIAL LOAD ACTS IN PLUS X DIRECTION
          POSITIVE AXIAL INTERNAL FORCE IS COMPRESSION
E>



     INPUT SEQUENCE COMPLETE.
     DO YOU WANT TO CONTINUE SOLUTION?  ENTER 'YES' OR 'NO'
I>y
     DO YOU WANT RESULTS PRINTED AT YOUR TERMINAL,
     WRITTEN TO A FILE, OR BOTH?
     ENTER 'TERMINAL', 'FILE', OR 'BOTH'
I>t
     SOLUTION COMPLETE
```

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 07:00:49

2.--DESIGN RESULTS

2.A.--HEADING

DESIGN OF ONE CELL CULVERT
WORKING STRESS DESIGN PROCEDURE
SHEAR DESIGN WITH COMBINATION OF UI440 AND ACI63
ONE LOAD CASE -- 1.5 TO .5 LOADING

2.B.--DESIGN THICKNESSES

DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

	DESIGN THICKNESS (IN)	<------CONTROLLING------> LOAD CASE	STRESS CONDITION	MEMBER
ROOF SLAB :	19.	1	SHEAR	21
EXTERIOR WALLS:	16.	1	SHEAR	11
BASE SLAB :	19.	1	SHEAR	1

CONCRETE AREA IN CROSS SECTION = 66.78 (SQFT)

2.C.--DESIGN REINFORCEMENT DATA FOR LEFT HALF OF SYSTEM

DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

MEMBER NUMBER 1

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.67	1	20.13	14.85	BOT	.44
3.17	1	-31.49	14.85	TOP	.97
5.67	1	-48.70	14.85	TOP	1.79
8.17	1	-31.49	14.85	TOP	.97
10.67	1	20.13	14.85	BOT	.44

```
MEMBER NUMBER 11
                        <------CONTROLLING------>
     DIST FROM          LOAD    BENDING     AXIAL          REINFORCEMENT
      LEFT END          CASE     MOMENT     FORCE        LOCATION      AREA
        (FT)                     (K-FT)    (KIPS)                     (SQIN)
         .79             1       -29.79     34.72          TOP          .64
        3.29             1        -9.52     34.22          TOP          MIN
        5.79             1        -3.13     33.72          TOP          MIN
        8.29             1        -9.62     33.22          TOP          MIN
       10.79             1       -28.03     32.72          TOP          .59

MEMBER NUMBER 21
                        <------CONTROLLING------>
     DIST FROM          LOAD    BENDING     AXIAL          REINFORCEMENT
      LEFT END          CASE     MOMENT     FORCE        LOCATION      AREA
        (FT)                     (K-FT)    (KIPS)                     (SQIN)
         .67             1       -18.36     12.31          TOP          .43
        3.17             1        30.30     12.31          BOT          .99
        5.67             1        46.52     12.31          BOT         1.75
        8.17             1        30.30     12.31          BOT          .99
       10.67             1       -18.36     12.31          TOP          .43



     DO YOU WANT DESIGN MEMBER LOAD/FORCE DATA OUTPUT?
     ENTER 'YES' OR 'NO'
I>n
     OUTPUT COMPLETE.
     DO YOU WANT TO EDIT INPUT DATA FOR THE PRECEDING PROBLEM?
     ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT TO MAKE ANOTHER RUN?  ENTER 'YES' OR 'NO'
I>n


     ********** NORMAL TERMINATION **********
```

```
     PROGRAM  CORTCUL  DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
     DATE: 08/22/80                                   TIME: 07:56:53

     ARE INPUT DATA TO BE READ FROM TERMINAL OR FILE?
     ENTER 'TERMINAL' OR 'FILE'
I>f
     ENTER INPUT FILE NAME (6 CHARACTERS MAXIMUM)
I>c1wd2
     INPUT COMPLETE. NO ERRORS DETECTED.
     DO YOU WANT TO EDIT INPUT DATA? ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA ECHOPRINTED TO YOUR
     TERMINAL, TO A FILE, TO BOTH, OR NEITHER?
     ENTER 'TERMINAL', 'FILE', 'BOTH', OR 'NEITHER'
I>f
     ENTER OUTPUT FILE NAME (6 CHARACTERS MAXIMUM)
I>c1wd20
     INPUT SEQUENCE COMPLETE.
     DO YOU WANT TO CONTINUE SOLUTION?  ENTER 'YES' OR 'NO'
I>y
     DO YOU WANT RESULTS PRINTED AT YOUR TERMINAL,
     WRITTEN TO FILE 'C1WD20', OR BOTH?
     ENTER 'TERMINAL', 'FILE', OR 'BOTH'
I>f
     SOLUTION COMPLETE
     DO YOU WANT DESIGN MEMBER LOAD/FORCE DATA OUTPUT?
     ENTER 'YES' OR 'NO'
I>y
     MEMBER LOAD/FORCE DATA ARE AVAILABLE FOR 2 LOAD CASES
     ENTER DESIRED LOAD CASE NUMBER (1 TO 2) OR 'ALL' OR 'NONE'
I>a
     WHICH MEMBER LOAD/FORCE DATA ARE DESIRED FOR LOAD CASE 1?
     ENTER LIST OR RANGE OF MEMBER NUMBERS, OR 'ALL', OR 'NONE', OR 'HELP'
I>1 11 21
     DO YOU WANT LOAD/FORCE DATA FOR OTHER MEMBERS FOR LOAD CASE 1?
     ENTER 'YES' OR 'NO'
I>n
     WHICH MEMBER LOAD/FORCE DATA ARE DESIRED FOR LOAD CASE 2?
     ENTER LIST OR RANGE OF MEMBER NUMBERS, OR 'ALL', OR 'NONE', OR 'HELP'
I>1 11 21
     DO YOU WANT LOAD/FORCE DATA FOR OTHER MEMBERS FOR LOAD CASE 2?
     ENTER 'YES' OR 'NO'
I>n
     OUTPUT COMPLETE.
     DO YOU WANT TO EDIT INPUT DATA FOR THE PRECEDING PROBLEM?
     ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT TO MAKE ANOTHER RUN?  ENTER 'YES' OR 'NO'
I>n


     ********** NORMAL TERMINATION **********
```

LISTING OF DATA FILE 'C1WD2'

```
1000 4 DESIGN OF ONE CELL CULVERT
1010   WORKING STRESS DESIGN PROCEDURE
1020   SHEAR DESIGN WITH COMBINATION OF UI440 AND ACI63
1030 TWO LOAD CASES -- CASE 1 = 1 TO 1, CASE 2 = 1.5 TO .5
1040 D WSD  2
1050 4000. 40000. 150.
1060 1 10. 0. 0. 10.
1070 4. 4. 4.
1080 12. 12. 12.
1090 2. 2. 2.
1100 1
1110 38. 125. 125.
1120 2 62.5
1130 1. 1. 0. -1000.
1140 1.5 .5 0. -1000.
1150 1. 1.
```

```
PROGRAM CORTCUL DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80                                         TIME: 07:57:36

1. INPUT DATA

1.A.--HEADING

DESIGN OF ONE CELL CULVERT
WORKING STRESS DESIGN PROCEDURE
SHEAR DESIGN WITH COMBINATION OF UI440 AND ACI63
TWO LOAD CASES -- CASE 1 = 1 TO 1, CASE 2 = 1.5 TO .5


1.B.--MODE AND PROCEDURE
     DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
     SHEAR DESIGN OPTION 2


1.C.--MATERIAL PROPERTIES

     CONCRETE:
          ULTIMATE STRENGTH      =  4000.      (PSI)
          WORKING STRESS         =  1800.      (PSI)
          MODULUS OF ELASTICITY  =     3.8E+06 (PSI)
          UNIT WEIGHT            =   150.      (PCF)


     REINFORCEMENT:
          YIELD STRENGTH         = 40000.      (PSI)
          WORKING STRESS         = 20000.      (PSI)
          MODULUS OF ELASTICITY  =    29.E+06  (PSI)


     MODULAR RATIO (ES/EC)       =      7.563


1.D.--GEOMETRY
     NO OF       CELL      HAUNCH      INVERT      CELL
     CELLS      HEIGHT      WIDTH       ELEV       WIDTH
                 (FT)       (IN)        (FT)        (FT)
       1        10.00       0.00        0.00       10.00


     REINFORCEMENT COVER (IN):          MINIMUM THICKNESS (IN):
     EXTERIOR SURFACES        = 4.00    ROOF SLAB       = 12.00
     INTERIOR ROOF/END WALLS  = 4.00    EXTERIOR WALLS  = 12.00
     INTERIOR BASE SLAB       = 4.00    BASE SLAB       = 12.00


     MAXIMUM REINF AREA  (SQIN):
     ROOF SLAB      = 2.00
     EXTERIOR WALLS = 2.00
     BASE SLAB      = 2.00
```

1.E.--LOAD DATA

1.E.1.--STANDARD LOAD CASES

SOIL DATA:

LAYER NO	ELEV AT TOP OF LAYER (FT)	SATURATED UNIT WEIGHT (PCF)	MOIST UNIT WEIGHT (PCF)
1	38.00	125.00	125.00

STANDARD LOAD CASE DATA
WATER UNIT WEIGHT = 62.5 (PCF)

LOAD CASE	PRESSURE COEFFICIENTS VERTICAL	PRESSURE COEFFICIENTS HORIZONTAL	SURFACE SURCHARGE (PSF)	GROUND WATER ELEVATION (FT)
1	1.00	1.00	0.00	-1000.00
2	1.50	.50	0.00	-1000.00

FOUNDATION REACTION COEFFICIENTS:
OUTER EDGES = 1.00
CENTERLINE = 1.00

1.E.2--SPECIAL LOAD CASES
NO SPECIAL LOAD CASES

1.E.4--INTERNAL WATER DATA
NO INTERNAL WATER

SCHEMATIC OF CULVERT:

```
*--21--*
!      !
!      !
11     12
!      !
!      !
*---1--*
```

LOCAL COORDINATE SYSTEMS:
HORIZONTAL MEMBERS: ORIGIN AT LEFT END, X-AXIS TO RIGHT, Y-AXIS UP
VERTICAL MEMBERS : ORIGIN AT BOTTOM, X-AXIS UP, Y-AXIS TO LEFT

SIGN CONVENTIONS:
POSITIVE LATERAL LOAD ACTS IN PLUS Y DIRECTION
POSITIVE BENDING MOMENT PRODUCES COMPRESSION
ON PLUS Y FACE OF MEMBER
POSITIVE SHEAR TENDS TO MOVE MEMBER IN PLUS Y DIRECTION
POSITIVE AXIAL LOAD ACTS IN PLUS X DIRECTION
POSITIVE AXIAL INTERNAL FORCE IS COMPRESSION

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 07:57:51

2.--DESIGN RESULTS

2.A.--HEADING

DESIGN OF ONE CELL CULVERT
WORKING STRESS DESIGN PROCEDURE
SHEAR DESIGN WITH COMBINATION OF UI440 AND ACI63
TWO LOAD CASES -- CASE 1 = 1 TO 1, CASE 2 = 1.5 TO .5

2.B.--DESIGN THICKNESSES
DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

	DESIGN THICKNESS (IN)	<------CONTROLLING------> LOAD CASE	STRESS CONDITION	MEMBER
ROOF SLAB :	19.	2	SHEAR	21
EXTERIOR WALLS:	18.	1	SHEAR	11
BASE SLAB :	19.	2	SHEAR	1

CONCRETE AREA IN CROSS SECTION = 71.17 (SQFT)

2.C.--DESIGN REINFORCEMENT DATA FOR LEFT HALF OF SYSTEM
DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

MEMBER NUMBER 1

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.75	1	32.65	29.53	BOT	.61
3.25	2	-29.94	14.89	TOP	.90
5.75	2	-47.25	14.89	TOP	1.72
8.25	2	-29.94	14.89	TOP	.90
10.75	1	32.65	29.53	BOT	.61

MEMBER NUMBER 11

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.79	1	-29.96	25.08	TOP	.70
3.29	2	-13.64	35.25	TOP	MIN
	1	10.14	24.52	BOT	MIN
5.79	2	-7.14	34.69	TOP	MIN
	1	22.50	23.95	BOT	.36
8.29	2	-13.54	34.12	TOP	MIN
	1	9.09	23.39	BOT	MIN
10.79	1	-28.16	22.83	TOP	.67

MEMBER NUMBER 21

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.75	1	-30.28	24.79	TOP	.63
3.25	2	28.68	12.27	BOT	.91
5.75	2	44.90	12.27	BOT	1.68
8.25	2	28.68	12.27	BOT	.91
10.75	1	-30.28	24.79	TOP	.63

3.--DESIGN MEMBER LOAD/FORCE DATA, LOAD CASE 1
DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

DESIGN LOAD/FORCE DATA FOR MEMBER 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	3.89	48.31	-22.34	29.53
.75	3.89	32.65	-19.43	29.53
3.25	3.89	-3.78	-9.71	29.53
5.75	3.89	-15.92	.00	29.53
8.25	3.89	-3.78	9.71	29.53
10.75	3.89	32.65	19.43	29.53
11.50	3.89	48.31	22.34	29.53

DESIGN LOAD/FORCE DATA FOR MEMBER 11

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-4.85	-48.76	25.65	25.26
.79	-4.75	-29.96	21.85	25.08
3.29	-4.44	10.14	10.36	24.52
5.79	-4.13	22.50	-.34	23.95
8.29	-3.81	9.09	-10.26	23.39
10.79	-3.50	-28.16	-19.40	22.83
11.58	-3.40	-44.60	-22.13	22.65

DESIGN LOAD/FORCE DATA FOR MEMBER 21

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-3.54	-44.55	20.35	24.79
.75	-3.54	-30.28	17.70	24.79
3.25	-3.54	2.90	8.85	24.79
5.75	-3.54	13.96	-.00	24.79
8.25	-3.54	2.90	-8.85	24.79
10.75	-3.54	-30.28	-17.70	24.79
11.50	-3.54	-44.55	-20.35	24.79

3.--DESIGN MEMBER LOAD/FORCE DATA, LOAD CASE 2
DESIGN USING WORKING STRESS DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 2

DESIGN LOAD/FORCE DATA FOR MEMBER 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	5.54	44.28	-31.84	14.89
.75	5.54	21.96	-27.68	14.89
3.25	5.54	-29.94	-13.84	14.89
5.75	5.54	-47.25	-.00	14.89
8.25	5.54	-29.94	13.84	14.89
10.75	5.54	21.96	27.68	14.89
11.50	5.54	44.28	31.84	14.89

DESIGN LOAD/FORCE DATA FOR MEMBER 11,

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-2.42	-43.50	12.95	35.99
.79	-2.38	-34.00	11.05	35.81
3.29	-2.22	-13.64	5.31	35.25
5.79	-2.06	-7.14	-.05	34.69
8.29	-1.91	-13.54	-5.01	34.12
10.79	-1.75	-31.85	-9.58	33.56
11.58	-1.70	-39.97	-10.94	33.38

DESIGN LOAD/FORCE DATA FOR MEMBER 21

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-5.19	-40.91	29.85	12.27
.75	-5.19	-19.98	25.95	12.27
3.25	-5.19	28.68	12.98	12.27
5.75	-5.19	44.90	.00	12.27
8.25	-5.19	28.68	-12.98	12.27
10.75	-5.19	-19.98	-25.95	12.27
11.50	-5.19	-40.91	-29.85	12.27

SIX CELL CULVERT DESIGN

BY ACI STRENGTH DESIGN PROCEDURE

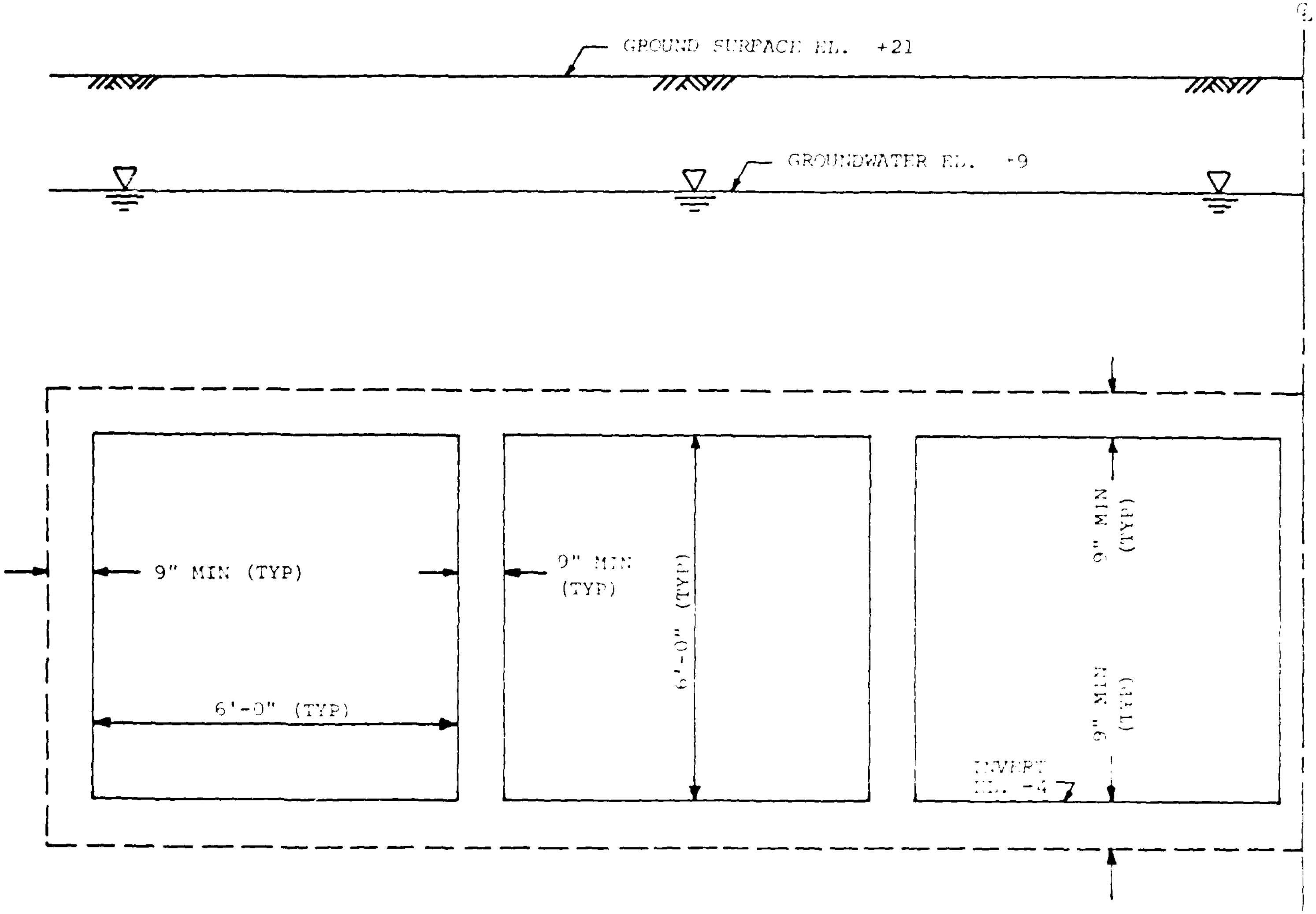


Figure B[illegible]. System for six-cell culvert design

```
     PROGRAM CORICUL  DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
     DATE: 08/22/80                                 TIME: 12:09:36

     ARE INPUT DATA TO BE READ FROM TERMINAL OR FILE?
     ENTER 'TERMINAL' OR 'FILE'
I>f
     ENTER INPUT FILE NAME (6 CHARACTERS MAXIMUM)
I>c6sdin
     INPUT COMPLETE. NO ERRORS DETECTED.
     DO YOU WANT TO EDIT INPUT DATA? ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA ECHOPRINTED TO YOUR
     TERMINAL, TO A FILE, TO BOTH, OR NEITHER?
     ENTER 'TERMINAL', 'FILE', 'BOTH', OR 'NEITHER'
I>f
     ENTER OUTPUT FILE NAME (6 CHARACTERS MAXIMUM)
I>c6sdot
     INPUT SEQUENCE COMPLETE.
     DO YOU WANT TO CONTINUE SOLUTION?  ENTER 'YES' OR 'NO'
I>y
     DO YOU WANT RESULTS PRINTED AT YOUR TERMINAL,
     WRITTEN TO FILE 'C6SDOT', OR BOTH?
     ENTER 'TERMINAL', 'FILE', OR 'BOTH'
I>f
     SOLUTION COMPLETE
     DO YOU WANT DESIGN MEMBER LOAD/FORCE DATA OUTPUT?
     ENTER 'YES' OR 'NO'
I>y
     MEMBER LOAD/FORCE DATA ARE AVAILABLE FOR 2 LOAD CASES
     ENTER DESIRED LOAD CASE NUMBER (1 TO 2) OR 'ALL' OR 'NONE'
I>a
     WHICH MEMBER LOAD/FORCE DATA ARE DESIRED FOR LOAD CASE 1?
     ENTER LIST OR RANGE OF MEMBER NUMBERS, OR 'ALL', OR 'NONE', OR 'HELP'
I>1 2 3 11 21 22 23
     DO YOU WANT LOAD/FORCE DATA FOR OTHER MEMBERS FOR LOAD CASE 1?
     ENTER 'YES' OR 'NO'
I>n
     WHICH MEMBER LOAD/FORCE DATA ARE DESIRED FOR LOAD CASE 2?
     ENTER LIST OR RANGE OF MEMBER NUMBERS, OR 'ALL', OR 'NONE', OR 'HELP'
I>1 2 3 11 21 22 23
     DO YOU WANT LOAD/FORCE DATA FOR OTHER MEMBERS FOR LOAD CASE 2?
     ENTER 'YES' OR 'NO'
I>n
     OUTPUT COMPLETE.
     DO YOU WANT TO EDIT INPUT DATA FOR THE PRECEDING PROBLEM?
     ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT TO MAKE ANOTHER RUN?  ENTER 'YES' OR 'NO'
I>n


     ********** NORMAL TERMINATION **********
```

LISTING OF INPUT DATA FILE 'C6SDIN'

```
1000 4 DESIGN OF SIX CELL CULVERT
1010 ACI STRENGTH DESIGN PROCEDURE
1020 SHEAR DESIGN BY ACI PROCEDURE
1030 TWO LOAD CASES -- CASE 1 = 1 TO 1, CASE 2 = 1.5 TO .5
1040 D SD 1
1050 3000 40000 150 .45 0
1070 6 6 0 -4  6
1070 3 3 3 0
1080 9 9 9 9
1100 .79 .79 .79 .79
1110 1
1120 21 125 125
1130 2 64
1140 1 1 0 9
1150 1.5 .5 0 9
1160 1 1
1170 1 1
```

```
PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80                                      TIME: 12:10:14

1. INPUT DATA

1.A.--HEADING

DESIGN OF SIX CELL CULVERT
ACI STRENGTH DESIGN PROCEDURE
SHEAR DESIGN BY ACI PROCEDURE
TWO LOAD CASES -- CASE 1 = 1 TO 1, CASE 2 = 1.5 TO .5


1.B.--MODE AND PROCEDURE
     DESIGN USING ACI STRENGTH DESIGN PROCEDURE, AND
     SHEAR DESIGN OPTION 1


1.C.--MATERIAL PROPERTIES

     CONCRETE:
          ULTIMATE STRENGTH      =  3000.       (PSI)
          ULTIMATE STRAIN        =      .003
          COMP. BLOCK RATIO      =      .85
          UNIT WEIGHT            =   150.       (PCF)


     REINFORCEMENT:
          YIELD STRENGTH         = 40000.       (PSI)
          MODULUS OF ELASTICITY  =    29.E+06   (PSI)
          MAXIMUM REINF RATIO    =      .45


     STRENGTH REDUCTION FACTOR  = VARIABLE


1.D.--GEOMETRY
     NO OF      CELL     HAUNCH      INVERT      CELL
     CELLS     HEIGHT     WIDTH       ELEV       WIDTH
                (FT)      (IN)        (FT)        (FT)
       6        6.00      0.00       -4.00       6.00


     REINFORCEMENT COVER (IN):           MINIMUM THICKNESS (IN):
     EXTERIOR SURFACES        = 3.00     ROOF SLAB       =  9.00
     INTERIOR ROOF/END WALLS  = 3.00     EXTERIOR WALLS  =  9.00
     INTERIOR BASE SLAB       = 3.00     BASE SLAB       =  9.00
     INTERIOR WALLS           =   CL     INTERIOR WALLS  =  9.00


     MAXIMUM REINF AREA  (SQIN):
     ROOF SLAB       =  .79
     EXTERIOR WALLS  =  .79
     BASE SLAB       =  .79
     INTERIOR WALLS  =  .79
```

1.E.--LOAD DATA

1.E.1.--STANDARD LOAD CASES

SOIL DATA:

LAYER NO	ELEV AT TOP OF LAYER (FT)	SATURATED UNIT WEIGHT (PCF)	MOIST UNIT WEIGHT (PCF)
1	21.00	125.00	125.00

STANDARD LOAD CASE DATA
WATER UNIT WEIGHT = 64.0 (PCF)

LOAD CASE	PRESSURE COEFFICIENTS VERTICAL	HORIZONTAL	SURFACE SURCHARGE (PSF)	GROUND WATER ELEVATION (FT)
1	1.00	1.00	0.00	9.00
2	1.50	.50	0.00	9.00

FOUNDATION REACTION COEFFICIENTS:
OUTER EDGES = 1.00
CENTERLINE = 1.00

1.E.2--SPECIAL LOAD CASES
NO SPECIAL LOAD CASES

1.E.3.--LOAD FACTORS FOR ACI STRENGTH DESIGN:
LIVE LOAD FACTOR = 1.00
DEAD LOAD FACTOR = 1.00

1.E.4--INTERNAL WATER DATA
NO INTERNAL WATER

SCHEMATIC OF CULVERT:

```
*--21--*--22--*--23--*--24--*--25--*--26--*
!      !      !      !      !      !      !
!      !      !      !      !      !      !
11     12     13     14     15     16     17
!      !      !      !      !      !      !
!      !      !      !      !      !      !
*---1--*---2--*---3--*---4--*---5--*---6--*
```

LOCAL COORDINATE SYSTEMS:
    HORIZONTAL MEMBERS: ORIGIN AT LEFT END, X-AXIS TO RIGHT, Y-AXIS UP
    VERTICAL MEMBERS : ORIGIN AT BOTTOM, X-AXIS UP, Y-AXIS TO LEFT

SIGN CONVENTIONS:
    POSITIVE LATERAL LOAD ACTS IN PLUS Y DIRECTION
    POSITIVE BENDING MOMENT PRODUCES COMPRESSION
        ON PLUS Y FACE OF MEMBER
    POSITIVE SHEAR TENDS TO MOVE MEMBER IN PLUS Y DIRECTION
    POSITIVE AXIAL LOAD ACTS IN PLUS X DIRECTION
    POSITIVE AXIAL INTERNAL FORCE IS COMPRESSION

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 12:10:27

2.--DESIGN RESULTS

2.A.--HEADING

DESIGN OF SIX CELL CULVERT
ACI STRENGTH DESIGN PROCEDURE
SHEAR DESIGN BY ACI PROCEDURE
TWO LOAD CASES -- CASE 1 = 1 TO 1, CASE 2 = 1.5 TO .5

2.B.--DESIGN THICKNESSES
DESIGN USING ACI STRENGTH DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 1

	DESIGN THICKNESS (IN)	CONTROLLING LOAD CASE	CONTROLLING STRESS CONDITION	CONTROLLING MEMBER
ROOF SLAB :	12.	2	SHEAR	21
EXTERIOR WALLS:	10.	1	SHEAR	11
BASE SLAB :	12.	2	SHEAR	1
INTERIOR WALLS:	9.	MINIMUM		

CONCRETE AREA IN CROSS SECTION = 115.33 (SQFT)

2.C.--DESIGN REINFORCEMENT DATA FOR LEFT HALF OF SYSTEM
DESIGN USING ACI STRENGTH DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 1

MEMBER NUMBER 1

DIST FROM LEFT END (FT)	CONTROLLING LOAD CASE	CONTROLLING BENDING MOMENT (K-FT)	CONTROLLING AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	REINFORCEMENT AREA (SQIN)
.42	1	8.80	12.00	BOT	.13
1.92	2	-4.84	7.59	TOP	.05
3.42	2	-7.57	7.59	TOP	.16
4.92	2	-2.54	7.59	TOP	MIN
6.42	2	10.25	7.59	BOT	.27

MEMBER NUMBER 2

DIST FROM LEFT END (FT)	<------CONTROLLING------ LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.38	2	10.80	7.77	BOT	.29
1.88	2	-1.28	7.77	TOP	MIN
3.38	2	-5.59	7.77	TOP	.07
4.88	2	-2.15	7.77	TOP	MIN
6.38	2	9.07	7.77	BOT	.21

MEMBER NUMBER 3

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.38	2	9.39	7.87	BOT	.23
1.88	2	-2.22	7.87	TOP	MIN
3.38	2	-6.07	7.87	TOP	.09
4.88	2	-2.15	7.87	TOP	MIN
6.38	2	9.54	7.87	BOT	.23

MEMBER NUMBER 11

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.50	1	-7.73	10.01	TOP	.20
2.00	2	-.72	12.21	TOP	MIN
	1	2.04	9.82	BOT	MIN
3.50	1	5.20	9.63	BOT	.07
5.00	2	-.45	11.84	TOP	MIN
	1	2.17	9.45	BOT	MIN
6.50	1	-6.63	9.26	TOP	.16

MEMBER NUMBER 12

DIST FROM LEFT END (FT)	<------CONTROLLING------> LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.50	2	-.29	24.29	TOP	MIN
2.00	2	-.02	24.12	TOP	MIN
3.50	1	-.10	16.19	TOP	MIN
	2	.25	23.95	BOT	MIN
5.00	2	.52	23.78	BOT	MIN
6.50	2	.79	23.62	BOT	MIN

MEMBER NUMBER 13

DIST FROM LEFT END (FT)	LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
	<------CONTROLLING------>				
.50	2	-.37	22.92	TOP	MIN
2.00	2	-.21	22.75	TOP	MIN
3.50	2	-.05	22.58	TOP	MIN
	1	.02	16.64	BOT	MIN
5.00	2	.10	22.41	BOT	MIN
6.50	2	.26	22.25	BOT	MIN

MEMBER NUMBER 14

DIST FROM LEFT END (FT).	LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
	<------CONTROLLING------>				
.50	2	-.00	23.29	TOP	MIN
2.00	2	-.00	23.12	TOP	MIN
3.50	2	-.00	22.95	TOP	MIN
	1	0.00	16.50	BOT	MIN
5.00	2	.00	22.78	BOT	MIN
6.50	2	.00	22.61	BOT	MIN

MEMBER NUMBER 21

DIST FROM LEFT END (FT)	LOAD CASE	BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
	<------CONTROLLING------>				
.42	1	-7.43	10.00	TOP	.11
1.92	2	5.34	5.97	BOT	.10
3.42	2	7.49	5.97	BOT	.18
4.92	2	2.15	5.97	BOT	MIN
6.42	2	-10.69	5.97	TOP	.31

MEMBER NUMBER 22

DIST FROM LEFT END (FT)	LOAD CASE	<------CONTROLLING------> BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.38	2	-10.17	5.79	TOP	.29
1.88	2	1.24	5.79	BOT	MIN
3.38	2	5.16	5.79	BOT	.09
4.88	2	1.57	5.79	BOT	MIN
6.38	2	-9.51	5.79	TOP	.27

MEMBER NUMBER 23

DIST FROM LEFT END (FT)	LOAD CASE	<------CONTROLLING------> BENDING MOMENT (K-FT)	AXIAL FORCE (KIPS)	REINFORCEMENT LOCATION	AREA (SQIN)
.38	2	-9.19	5.69	TOP	.25
1.88	2	1.93	5.69	BOT	MIN
3.38	2	5.55	5.69	BOT	.11
4.88	2	1.67	5.69	BOT	MIN
6.38	2	-9.70	5.69	TOP	.28

3.--DESIGN MEMBER LOAD/FORCE DATA, LOAD CASE 1
DESIGN USING ACI STRENGTH DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 1

DESIGN LOAD/FORCE DATA FOR MEMBER 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	2.52	12.34	-9.02	12.00
.42	2.52	8.80	-7.97	12.00
1.92	2.52	-.33	-4.20	12.00
3.42	2.52	-3.79	-.42	12.00
4.92	2.52	-1.59	3.36	12.00
6.42	2.52	6.28	7.13	12.00
6.79	2.52	9.13	8.08	12.00

DESIGN LOAD/FORCE DATA FOR MEMBER 2

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	2.52	9.84	-8.51	12.17
.38	2.52	6.83	-7.56	12.17
1.88	2.52	-1.68	-3.79	12.17
3.38	2.52	-4.53	-.01	12.17
4.88	2.52	-1.71	3.77	12.17
6.38	2.52	6.77	7.54	12.17
6.75	2.52	9.78	8.49	12.17

DESIGN LOAD/FORCE DATA FOR MEMBER 3

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	2.52	10.12	-8.55	12.28
.38	2.52	7.09	-7.61	12.28
1.88	2.52	-1.49	-3.83	12.28
3.38	2.52	-4.40	-.05	12.28
4.88	2.52	-1.64	3.72	12.28
6.38	2.52	6.78	7.50	12.28
6.75	2.52	9.77	8.45	12.28

DESIGN LOAD/FORCE DATA FOR MEMBER 11

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-3.19	-12.53	10.39	10.07
.50	-3.13	-7.73	8.81	10.01
2.00	-2.94	2.04	4.26	9.82
3.50	-2.75	5.20	-.00	9.63
5.00	-2.56	2.17	-3.99	9.45
6.50	-2.38	-6.63	-7.69	9.26
7.00	-2.31	-10.77	-8.86	9.20

DESIGN LOAD/FORCE DATA FOR MEMBER 21

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-2.40	-10.69	8.32	10.00
.42	-2.40	-7.43	7.32	10.00
1.92	-2.40	.85	3.72	10.00
3.42	-2.40	3.74	.12	10.00
4.92	-2.40	1.22	-3.48	10.00
6.42	-2.40	-6.70	-7.08	10.00
6.79	-2.40	-9.52	-7.98	10.00

DESIGN LOAD/FORCE DATA FOR MEMBER 22

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-2.40	-9.01	7.93	9.83
.38	-2.40	-6.20	7.03	9.83
1.88	-2.40	1.65	3.43	9.83
3.38	-2.40	4.09	-.17	9.83
4.88	-2.40	1.14	-3.77	9.83
6.38	-2.40	-7.22	-7.37	9.83
6.75	-2.40	-10.15	-8.27	9.83

DESIGN LOAD/FORCE DATA FOR MEMBER 23

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-2.40	-9.77	8.09	9.72
.38	-2.40	-6.90	7.19	9.72
1.88	-2.40	1.19	3.59	9.72
3.38	-2.40	3.88	-.01	9.72
4.88	-2.40	1.17	-3.61	9.72
6.38	-2.40	-6.95	-7.21	9.72
6.75	-2.40	-9.82	-8.11	9.72

3.--DESIGN MEMBER LOAD/FORCE DATA, LOAD CASE 2
DESIGN USING ACI STRENGTH DESIGN PROCEDURE, AND
SHEAR DESIGN OPTION 1

DESIGN LOAD/FORCE DATA FOR MEMBER 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	3.45	9.96	-11.03	7.59
.42	3.45	5.66	-9.59	7.59
1.92	3.45	-4.84	-4.41	7.59
3.42	3.45	-7.57	.76	7.59
4.92	3.45	-2.54	5.94	7.59
6.42	3.45	10.25	11.12	7.59
6.79	3.45	14.66	12.41	7.59

DESIGN LOAD/FORCE DATA FOR MEMBER 2

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	3.45	15.04	-11.94	7.77
.38	3.45	10.80	-10.64	7.77
1.88	3.45	-1.28	-5.47	7.77
3.38	3.45	-5.59	-.29	7.77
4.88	3.45	-2.15	4.89	7.77
6.38	3.45	9.07	10.06	7.77
6.75	3.45	13.08	11.36	7.77

DESIGN LOAD/FORCE DATA FOR MEMBER 3

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	3.45	13.50	-11.62	7.87
.38	3.45	9.39	-10.33	7.87
1.88	3.45	-2.22	-5.15	7.87
3.38	3.45	-6.07	.03	7.87
4.88	3.45	-2.15	5.20	7.87
6.38	3.45	9.54	10.38	7.87
6.75	3.45	13.67	11.67	7.87

DESIGN LOAD/FORCE DATA FOR MEMBER 11

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-2.03	-9.92	6.56	12.46
.50	-1.98	-6.89	5.56	12.40
2.00	-1.84	-.72	2.70	12.21
3.50	-1.70	1.32	.05	12.03
5.00	-1.55	-.45	-2.38	11.84
6.50	-1.41	-5.73	-4.61	11.65
7.00	-1.36	-8.20	-5.30	11.59

DESIGN LOAD/FORCE DATA FOR MEMBER 21

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-3.33	-8.33	10.32	5.97
.42	-3.33	-4.31	8.94	5.97
1.92	-3.33	5.34	3.94	5.97
3.42	-3.33	7.49	-1.06	5.97
4.92	-3.33	2.15	-6.06	5.97
6.42	-3.33	-10.69	-11.06	5.97
6.79	-3.33	-15.08	-12.31	5.97

DESIGN LOAD/FORCE DATA FOR MEMBER 22

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-3.33	-14.20	11.36	5.79
.38	-3.33	-10.17	10.11	5.79
1.88	-3.33	1.24	5.11	5.79
3.38	-3.33	5.16	.11	5.79
4.88	-3.33	1.57	-4.89	5.79
6.38	-3.33	-9.51	-9.89	5.79
6.75	-3.33	-13.45	-11.14	5.79

DESIGN LOAD/FORCE DATA FOR MEMBER 23

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-3.33	-13.14	11.16	5.69
.38	-3.33	-9.19	9.91	5.69
1.88	-3.33	1.93	4.91	5.69
3.38	-3.33	5.55	-.09	5.69
4.88	-3.33	1.67	-5.08	5.69
6.38	-3.33	-9.70	-10.08	5.69
6.75	-3.33	-13.72	-11.33	5.69

THREE CELL CULVERT INVESTIGATION

BY ACI STRENGTH DESIGN PROCEDURE

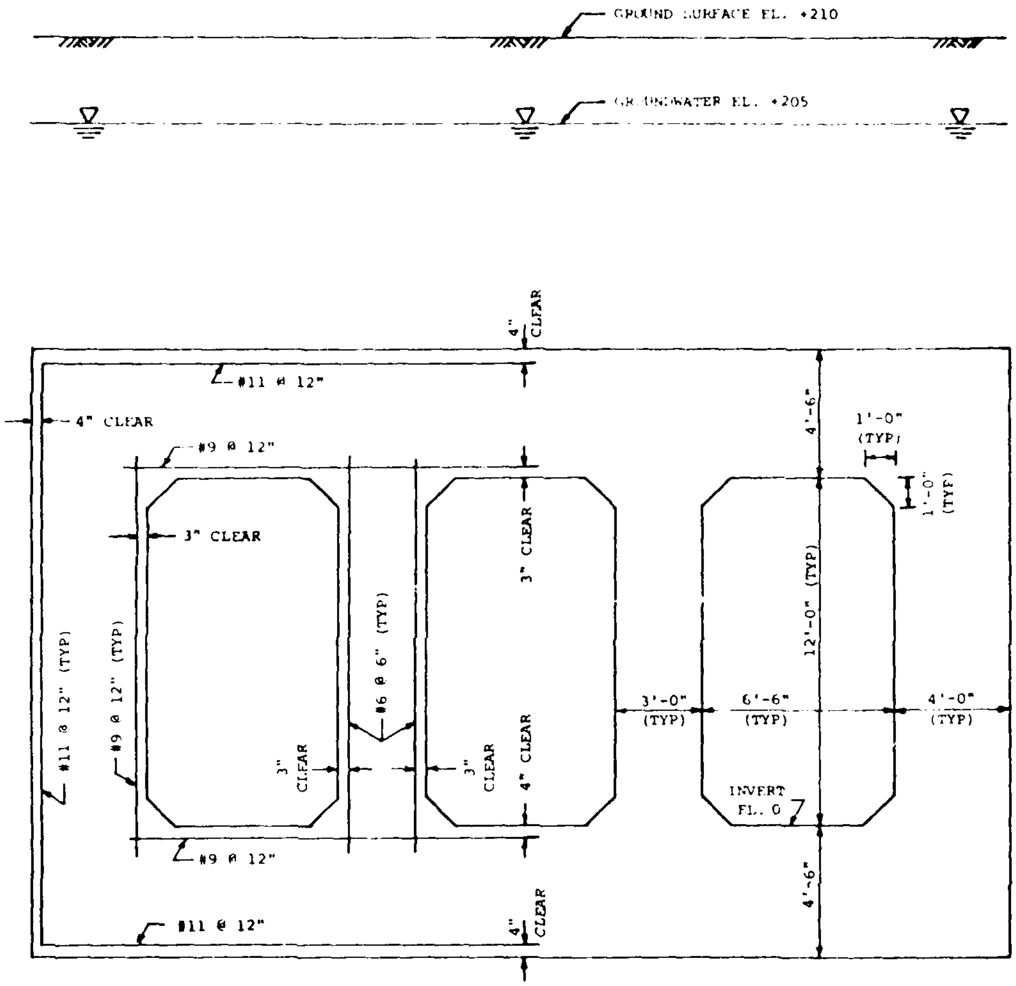


Figure B3. System for investigation of three cell culvert

```
     PROGRAM CORTCUL DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
     DATE: 08/22/80                                 TIME: 15:00:52

     ARE INPUT DATA TO BE READ FROM TERMINAL OR FILE?
     ENTER 'TERMINAL' OR 'FILE'
I f
     ENTER INPUT FILE NAME (6 CHARACTERS MAXIMUM)
I c3sdin
     INPUT COMPLETE. NO ERRORS DETECTED.
     DO YOU WANT TO EDIT INPUT DATA? ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA ECHOPRINTED TO YOUR
     TERMINAL, TO A FILE, TO BOTH, OR NEITHER?
     ENTER 'TERMINAL', 'FILE', 'BOTH', OR 'NEITHER'
I f
     ENTER OUTPUT FILE NAME (6 CHARACTERS MAXIMUM)
I c3sdot
     INPUT SEQUENCE COMPLETE.
     DO YOU WANT TO CONTINUE SOLUTION?  ENTER 'YES' OR 'NO'
I>y
     DO YOU WANT RESULTS PRINTED AT YOUR TERMINAL,
     WRITTEN TO FILE 'C3SDOT', OR BOTH?
     ENTER 'TERMINAL', 'FILE', OR 'BOTH'
I>f
     DO YOU WANT MEMBER LOAD/FORCE DATA OUTPUT?
     ENTER 'YES' OR 'NO'
I y
     RESULTS ARE AVAILABLE FOR 2 STANDARD LOAD CASES
     ENTER DESIRED LOAD CASE (1 TO 2)
I 1
     RESULTS ARE AVAILABLE FOR FOLLOWING MEMBERS
         1    2   11   12   21   22
     RESULTS ARE AVAILABLE FOR  6 MEMBERS
     ENTER LIST OF MEMBER NUMBERS (UP TO  6 MEMBERS) OR 'NONE'
I>1
     DO YOU WANT RESULTS FOR OTHER MEMBERS?  ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT RESULTS FOR ANOTHER LOAD CASE?  ENTER 'YES' OR 'NO'
I>y
     RESULTS ARE AVAILABLE FOR 2 STANDARD LOAD CASES
     ENTER DESIRED LOAD CASE (1 TO 2)
I>2
     RESULTS ARE AVAILABLE FOR FOLLOWING MEMBERS
         1    2   11   12   21   22
     RESULTS ARE AVAILABLE FOR  6 MEMBERS
     ENTER LIST OF MEMBER NUMBERS (UP TO  6 MEMBERS) OR 'NONE'
I>21
     DO YOU WANT RESULTS FOR OTHER MEMBERS?  ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT RESULTS FOR ANOTHER LOAD CASE?  ENTER 'YES' OR 'NO'
I>n
     OUTPUT COMPLETE.
     DO YOU WANT TO EDIT INPUT DATA FOR THE PRECEDING PROBLEM?
     ENTER 'YES' OR 'NO'
I n
     DO YOU WANT TO MAKE ANOTHER RUN?  ENTER 'YES' OR 'NO'
I>n
     ********** NORMAL TERMINATION **********
```

LISTING OF INPUT DATA FILE 'C3SDIN'

```
1000 2 INVESTIGATION OF THREE CELL CONDUIT
1010 USING ACI STRENGTH DESIGN PROCEDURE AND TWO LOAD CASES
1020 I SD
1030 4000 40000 150 .5 0
1040 3 12 12 0 6.5
1050 4.71 3.56 4.56 3.38
1060 54 48 54 36
1070 1
1080 210 140 135
1090 2
1100 1 1 0 205
1110 1.5 .5 0 205
1110 0
1120 1 1
1130 0
1150 6
1160 1 1 1.56 1 1.56 1 1.56
1170 2 1 1.56 1 1.56 1 1.56
1180 11 1.56 1 1.56 1 1.56 1
1190 12 .88 .88 .88 .88 .88 .88
1200 21 1.56 1 1.56 1 1.56 1
1210 22 1.56 1 1.56 1 1.56 1
```

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 15:01:30

1. INPUT DATA

1.A.--HEADING

INVESTIGATION OF THREE CELL CONDUIT
USING ACI STRENGTH DESIGN PROCEDURE AND TWO LOAD CASES

1.B.--MODE AND PROCEDURE

INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

1.C.--MATERIAL PROPERTIES

CONCRETE:

ULTIMATE STRENGTH	=	4000.	(PSI)
ULTIMATE STRAIN	=	.003	
COMP. BLOCK RATIO	=	.85	
UNIT WEIGHT	=	150.	(PCF)

REINFORCEMENT:

YIELD STRENGTH	=	40000.	(PSI)
MODULUS OF ELASTICITY	=	29.E+06	(PSI)
MAXIMUM REINF RATIO	=	.50	

STRENGTH REDUCTION FACTOR = VARIABLE

1.D.--GEOMETRY

NO OF CELLS	CELL HEIGHT (FT)	HAUNCH WIDTH (IN)	INVERT ELEV (FT)	CELL WIDTH (FT)
3	12.00	12.00	0.00	6.50

REINFORCEMENT COVER (IN):		THICKNESS (IN):	
EXTERIOR SURFACES	= 4.71	ROOF SLAB	= 54.00
INTERIOR ROOF/END WALLS	= 3.56	EXTERIOR WALLS	= 48.00
INTERIOR BASE SLAB	= 4.56	BASE SLAB	= 54.00
INTERIOR WALLS	= 3.38	INTERIOR WALLS	= 36.00

1.E.--LOAD DATA

1.E.1.--STANDARD LOAD CASES

SOIL DATA:

LAYER NO	ELEV AT TOP OF LAYER (FT)	SATURATED UNIT WEIGHT (PCF)	MOIST UNIT WEIGHT (PCF)
1	210.00	140.00	135.00

STANDARD LOAD CASE DATA
WATER UNIT WEIGHT = 62.5 (PCF)

LOAD CASE	PRESSURE COEFFICIENTS VERTICAL	PRESSURE COEFFICIENTS HORIZONTAL	SURFACE SURCHARGE (PSF)	GROUND WATER ELEVATION (FT)
1	1.00	1.00	0.00	205.00
2	1.50	.50	0.00	205.00

1.E.2--SPECIAL LOAD CASES
NO SPECIAL LOAD CASES

1.E.3.--LOAD FACTORS FOR ACI STRENGTH DESIGN:
LIVE LOAD FACTOR = 1.00
DEAD LOAD FACTOR = 1.00

1.E.4--INTERNAL WATER DATA
NO INTERNAL WATER

1.F.--REINFORCEMENT AREAS (SQIN) FOR INVESTIGATION

MEMBER	LEFT END		CENTERLINE		RIGHT END	
NO	TOP	BOTTOM	TOP	BOTTOM	TOP	BOTTOM
1	1.00	1.56	1.00	1.56	1.00	1.56
2	1.00	1.56	1.00	1.56	1.00	1.56
11	1.56	1.00	1.56	1.00	1.56	1.00
12	.88	.88	.88	.88	.88	.88
21	1.56	1.00	1.56	1.00	1.56	1.00
22	1.56	1.00	1.56	1.00	1.56	1.00

```
                    SCHEMATIC OF CULVERT:

                    *--21--*--22--*--23--*
                    !      !      !      !
                    !      !      !      !
                   11     12     13     14
                    !      !      !      !
                    !      !      !      !
                    *---1--*---2--*---3--*


LOCAL COORDINATE SYSTEMS:
     HORIZONTAL MEMBERS: ORIGIN AT LEFT END, X-AXIS TO RIGHT, Y-AXIS UP
     VERTICAL MEMBERS  : ORIGIN AT BOTTOM, X-AXIS UP, Y-AXIS TO LEFT

SIGN CONVENTIONS:
     POSITIVE LATERAL LOAD ACTS IN PLUS Y DIRECTION
     POSITIVE BENDING MOMENT PRODUCES COMPRESSION
          ON PLUS Y FACE OF MEMBER
     POSITIVE SHEAR TENDS TO MOVE MEMBER IN PLUS Y DIRECTION
     POSITIVE AXIAL LOAD ACTS IN PLUS X DIRECTION
     POSITIVE AXIAL INTERNAL FORCE IS COMPRESSION
     UNLESS OTHERWISE NOTED, FACTOR OF SAFETY FOR
          INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE
          IS DEFINED BY  FS = PHI * PN / P
               WHERE  PN = ULTIMATE STRENGTH AT ACTUAL ECCENTRICITY
                       P = ACTUAL AXIAL FORCE
```

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 15:01:44

2.A.--HEADING

INVESTIGATION OF THREE CELL CONDUIT
USING ACI STRENGTH DESIGN PROCEDURE AND TWO LOAD CASES

2.B.--SUMMARY OF RESULTS FOR STANDARD LOAD CASE 1
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

MEMBER 1		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	351.33	60.63	70.88
AXIAL FORCE	(KIPS)	306.99	306.99	306.99
FLEXURE FACTOR OF SAFETY		3.78	4.19	5.08
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		-107.97		21.67
SHEAR FS AT 0.15LN (UI440)		5.43		------

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER
------ - SHEAR FS IS GREATER THAN TEN

MEMBER 2		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	18.66	-131.82	18.66
AXIAL FORCE	(KIPS)	307.18	307.18	307.18
FLEXURE FACTOR OF SAFETY		5.08	4.19	5.08
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		-64.82		64.82
SHEAR FS AT 0.15LN (UI440)		9.08		9.08

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

MEMBER 11		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-233.78	282.80	-227.89
AXIAL FORCE	(KIPS)	248.36	244.75	241.16
FLEXURE FACTOR OF SAFETY		4.50	2.84	4.63
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		120.73		-118.96
SHEAR FS AT 0.15LN (UI440)		3.54		3.57

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

MEMBER 12		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-12.06	-10.90	-9.73
AXIAL FORCE	(KIPS)	226.52	223.82	221.12
FLEXURE FACTOR OF SAFETY		5.00	3.84	5.12
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		.19		.19
SHEAR FS AT 0.15LN (UI440)		------		------

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

------ - SHEAR FS IS GREATER THAN TEN

MEMBER 21		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-346.18	-65.13	-77.08
AXIAL FORCE	(KIPS)	292.25	292.25	292.25
FLEXURE FACTOR OF SAFETY		3.90	4.40	5.34
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		104.51		-21.71
SHEAR FS AT 0.15LN (UI440)		5.53		------

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

------ - SHEAR FS IS GREATER THAN TEN

MEMBER 22		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-24.28	122.22	-24.23
AXIAL FORCE	(KIPS)	292.06	292.06	292.06
FLEXURE FACTOR OF SAFETY		5.34	4.40	5.34
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		63.11		-63.11
SHEAR FS AT 0.15LN (UI440)		9.40		9.40

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

2.B.--SUMMARY OF RESULTS FOR STANDARD LOAD CASE 2
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

MEMBER 1		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	214.41	-42.27	82.72
AXIAL FORCE	(KIPS)	220.67	220.67	220.67
FLEXURE FACTOR OF SAFETY		5.74	5.83	7.07
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN	(KIPS)	-102.46		61.95
SHEAR FS AT 0.15LN	(UI440)	5.22		8.63

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

MEMBER 2		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	62.06	-128.78	62.06
AXIAL FORCE	(KIPS)	220.88	220.88	220.88
FLEXURE FACTOR OF SAFETY		7.06	5.52	7.06
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN	(KIPS)	-82.21		82.21
SHEAR FS AT 0.15LN	(UI440)	6.53		6.53

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

MEMBER 11		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-209.94	162.35	-202.87
AXIAL FORCE	(KIPS)	280.88	277.28	273.68
FLEXURE FACTOR OF SAFETY		4.42	3.77	4.55
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN	(KIPS)	86.92		-85.1[illegible]
SHEAR FS AT 0.15LN	(UI440)	4.92		4.99

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

MEMBER 12		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-9.25	-8.01	-6.76
AXIAL FORCE	(KIPS)	322.00	319.30	316.60
FLEXURE FACTOR OF SAFETY		3.52	2.69	3.58
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		.21		.21
SHEAR FS AT 0.15LN (UI440)		------		------

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

------ - SHEAR FS IS GREATER THAN TEN

MEMBER 21		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-209.14	37.89	-88.81
AXIAL FORCE	(KIPS)	209.54	209.54	209.54
FLEXURE FACTOR OF SAFETY		5.98	6.14	7.45
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		99.01		-61.98
SHEAR FS AT 0.15LN (UI440)		5.33		8.51

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

MEMBER 22		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-67.33	119.53	-67.33
AXIAL FORCE	(KIPS)	209.33	209.33	209.33
FLEXURE FACTOR OF SAFETY		7.45	5.87	7.45
STRENGTH REDUCTION (PHI)		.70	.70	.70
SHEAR FORCE AT D	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT D (ACI63)		NNNNNN		NNNNNN
SHEAR FORCE AT 0.15LN (KIPS)		80.49		-80.49
SHEAR FS AT 0.15LN (UI440)		6.73		6.73

NNNNNN - ACI63 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 15:01:34

3.A.--HEADING

INVESTIGATION OF THREE CELL CONDUIT
USING ACI STRENGTH DESIGN PROCEDURE AND TWO LOAD CASES

3.B.--RESULTS FOR STANDARD LOAD CASE 1
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

RESULTS FOR MEMBER 1, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	28.49	679.81	-192.73	306.99
2.00	28.49	351.33	-135.75	306.99
3.00	28.49	229.83	-107.25	306.99
4.13	28.49	127.20	-75.20	306.99
5.25	28.49	60.63	-43.15	306.99
6.38	28.49	30.12	-11.09	306.99
7.50	28.49	35.68	20.96	306.99
8.50	28.49	70.88	49.45	306.99
10.00	28.49	177.12	92.19	306.99

3.B.--RESULTS FOR STANDARD LOAD CASE 2
INVESTIGATION USING ACI STRENGTH DESIGN PROCEDURE

RESULTS FOR MEMBER 21, LOAD CASE 2

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL FORCE (KIPS)
0.00	-35.38	-546.91	204.27	209.54
2.00	-35.38	-209.14	133.50	209.54
3.00	-35.38	-93.33	98.12	209.54
4.13	-35.38	-5.33	58.32	209.54
5.25	-35.38	37.89	18.51	209.54
6.38	-35.38	36.32	-21.29	209.54
7.50	-35.38	-10.02	-61.10	209.54
8.50	-35.38	-88.81	-96.48	209.54
10.00	-35.38	-273.33	-149.55	209.54

FOUR CELL CULVERT INVESTIGATION

BY WORKING STRESS DESIGN PROCEDURE

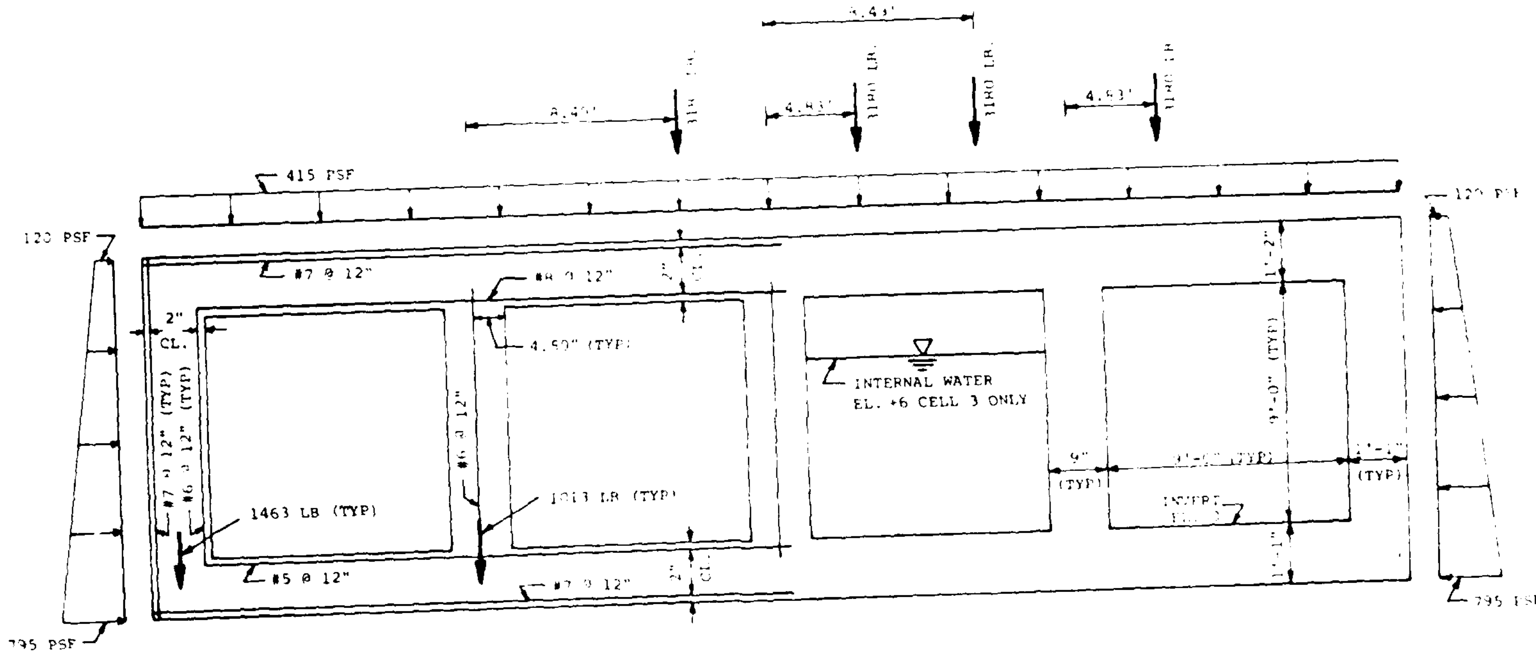


Figure B4. System for investigation of four cell culvert

```
[illegible] DESIGN [illegible]ATION OF [illegible]
DATE: [illegible]                                   TIME: [illegible]

    [illegible] INPUT DATA TO BE READ FROM TERMINAL OR FILE?
    ENTER TERMINAL OR FILE
I [illegible]

    ENTER NUMBER OF HEADER LINES (1 TO 4)
I 4
    ENTER HEADER LINE 1 (72 CHARACTERS MAXIMUM)
I investigation of four cell culvert
    ENTER HEADER LINE 2 (72 CHARACTERS MAXIMUM)
I with working stress design procedure
    ENTER HEADER LINE 3 (72 CHARACTERS MAXIMUM)
I one special load case with
    ENTER HEADER LINE 4 (72 CHARACTERS MAXIMUM)
I concentrated loads on roof and internal water
    MODE? ENTER 'DESIGN' OR 'INVESTIGATION'
I I
    METHOD? ENTER 'WSD' OR 'SD'
I wsd
    MATERIAL PROPERTIES, ENTER VALUES UNDER HEADINGS
                CONCRETE          REINF         CONCRETE
               COMPRESSIVE        YIELD           UNIT
                STRENGTH        STRENGTH         WEIGHT
                  (PSI)           (PSI)          (PCF)
I                 4000.           40000.          150.
    GEOMETRY DATA
          NO OF        CELL       HAUNCH      INVERT       CELL
          CELLS       HEIGHT      WIDTH        ELEV       WIDTH
         (1 TO 9)      (FT)        (IN)        (FT)        (FT)
                                                         ***** ENTER ZERO IF VARIABLE
I           4           9.          0.          0.          9.
    COVER TO CENTROID OF REINFORCEMENT
          EXTERIOR              INTERIOR SURFACES              INTERIOR
          SURFACES        ROOF EXT.WALLS      BASE SLAB          WALLS
            (IN)               (IN)             (IN)             (IN)
I           2.44               2.5              2.63             0.
    SLAB THICKNESSES
              ROOF         EXTERIOR       BASE       INTERIOR
              SLAB          WALLS         SLAB        WALLS
              (IN)          (IN)          (IN)        (IN)
I             14.           13.           13.          9.
    STANDARD LOAD DATA, ENTER NUMBER OF SOIL LAYERS (0 TO 3)
I 0
    ENTER NUMBER OF SPECIAL LOAD CASES (1 TO 4)
I 1
```

```
     ENTER NUMBER OF MEMBER LOAD DATA LINES
     FOR SPECIAL LOAD CASE 1 (1 TO 24)
I> 20
     ENTER DATA FOR 20 LOADED MEMBERS
     MEM      LOAD          LOAD         MAX        DISTANCE TO        NEGATIVE
     NO    DIRECTION        TYPE         LOAD       START    END*       END**
              (X,Y)        (C,U,T)      (PSF)       (FT)     (FT)       (L,R)
                                                  * OMIT IF LOAD TYPE
                                                 ** OMIT IF LOAD TYPE
I    21        y             u       -415.0000   -.5400    9.7200
I>   22        y             u       -415.0000   0.0000    [illegible]
I>   23        y             u       -415.0000   0.0000    [illegible]
I    24        y             u       -415.0000   0.0000   10.4500
I    22        y             c      -3180.0000   8.4900
I    23        y             c      -3180.0000   4.8300
I    23        y             c      -3180.0000   8.4900
I    24        y             c      -3180.0000   4.8300
I>   11        y             t        795.0000   -.5400   10.7100       L
I>   11        y             t       -120.0000   -.5400   10.7100       R
I>   15        y             t        795.0000   -.5400   10.7100       L
I>   15        y             t        120.0000   -.5400   10.7100       R
I>   11        x             u       -162.5000    .5400    9.5400
I>   12        x             u       -112.5000    .5400    9.5400
I>   13        x             u       -112.5000    .5400    9.5400
I>   14        x             u       -112.5000    .5400    9.5400
I>   15        x             u       -162.5000    .5400    9.5400
I>   13        y             t        375.0000    .5400    6.5400       L
I>    3        y             u       -375.0000    .3750    9.3750
I>   14        y             t       -375.0000    .5400    6.5400       L
     MEMBER DATA FOR INVESTIGATION
     ENTER NUMBER OF MEMBERS TO BE INVESTIGATED (1 TO 13 )
I>0
     MEMBER DATA FOR INVESTIGATION
     ENTER NUMBER OF MEMBERS TO BE INVESTIGATED (1 TO 13 )
I>8
     ENTER  8 LINES OF MEMBER REINFORCEMENT AREAS (SQIN)
          MEMBER           LEFT END             CENTERLINE            RIGHT END
          NUMBER       TOP        BOTTOM     TOP        BOTTOM      TOP        BOTTOM
I>          23          .6          .79       .6          .79        .6          .79
I>          24          .6          .79       .6          .79        .6          .79
I>          14         .44          .44      .44          .44       .44          .44
I>          15         .44           .6      .44           .6       .44           .6
I>           1         .31           .6      .31           .6       .31           .6
I>           2         .31           .6      .31           .6       .31           .6
I>           3         .31           .6      .31           .6       .31           .6
I>           4         .31           .6      .31           .6       .31           .6
     INPUT COMPLETE. NO ERRORS DETECTED.
     DO YOU WANT TO EDIT INPUT DATA? ENTER 'YES' OR 'NO'
I>n
     DO YOU WANT INPUT DATA SAVED IN A FILE? ENTER 'YES' OR 'NO'
I>n
```

LISTING OF INPUT DATA FILE FOR FOUR CELL CULVERT INVESTIGATION

```
1000 4 INVESTIGATION OF FOUR CELL CULVERT
1010   WITH WORKING STRESS DESIGN PROCEDURE
1020   ONE SPECIAL LOAD CASE WITH
1030   CONCENTRATED LOADS ON ROOF AND INTERNAL WATER
1040 I WSD
 1050 4000. 40000. 150.
 1060 4 9. 0. 0. 9.
 1070 2.44 2.5 2.63 0.
 1080 14. 13. 13. 9.
 1090 0
 1100 1
 1110 20
1120 21 Y U    -415.0000         -.5400        9.9200
1130 22 Y U    -415.0000         0.0000        9.7500
1140 23 Y U    -415.0000         0.0000        9.7500
1150 24 Y U    -415.0000         0.0000       10.4600
1160 22 Y C   -3180.0000         8.4900
1170 23 Y C   -3180.0000         4.8300
1180 23 Y C   -3180.0000         8.4900
1190 24 Y C   -3180.0000         4.8300
1200 11 Y T    -795.0000         -.5400       10.7100 L
1210 11 Y T    -120.0000         -.5400       10.7100 R
1220 15 Y T     795.0000         -.5400       10.7100 L
1230 15 Y T     120.0000         -.5400       10.7100 R
1240 11 X U    -162.5000          .5400        9.5400
1250 12 X U    -112.5000          .5400        9.5400
1260 13 X U    -112.5000          .5400        9.5400
1270 14 X U    -112.5000          .5400        9.5400
1280 15 X U    -162.5000          .5400        9.5400
1290 13 Y T     375.0000          .5400        6.5400 L
1300  3 Y U    -375.0000          .3750        9.3750
1310 14 Y T    -375.0000          .5400        6.5400 L
 1330 0
 1340 8
 1350 23 .6 .79 .6 .79 .6 .79
 1360 24 .6 .79 .6 .79 .6 .79
 1370 14 .44 .44 .44 .44 .44 .44
 1380 15 .44 .6 .44 .6 .44 .6
 1390 1 .31 .6 .31 .6 .31 .6
 1400 2 .31 .6 .31 .6 .31 .6
 1410 3 .31 .6 .31 .6 .31 .6
 1420 4 .31 .6 .31 .6 .31 .6
```

```
PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80                                         TIME: 15:33:49

1. INPUT DATA

1.A.--HEADING

INVESTIGATION OF FOUR CELL CULVERT
WITH WORKING STRESS DESIGN PROCEDURE
ONE SPECIAL LOAD CASE WITH
CONCENTRATED LOADS ON ROOF AND INTERNAL WATER


1.B.--MODE AND PROCEDURE
     INVESTIGATION USING WORKING STRESS DESIGN PROCEDURE


1.C.--MATERIAL PROPERTIES

     CONCRETE:
          ULTIMATE STRENGTH      =  4000.      (PSI)
          WORKING STRESS         =  1800.      (PSI)
          MODULUS OF ELASTICITY  =     3.8E+06 (PSI)
          UNIT WEIGHT            =   150.      (PCF)


     REINFORCEMENT:
          YIELD STRENGTH         = 40000.      (PSI)
          WORKING STRESS         = 20000.      (PSI)
          MODULUS OF ELASTICITY  =    29.E+06  (PSI)


     MODULAR RATIO (ES/EC)       =      7.563


1.D.--GEOMETRY
     NO OF      CELL     HAUNCH      INVERT      CELL
     CELLS     HEIGHT     WIDTH       ELEV      WIDTH
                (FT)      (IN)        (FT)       (FT)
       4        9.00      0.00        0.00       9.00


     REINFORCEMENT COVER (IN):           THICKNESS (IN):
     EXTERIOR SURFACES       = 2.44      ROOF SLAB      = 14.00
     INTERIOR ROOF/END WALLS = 2.50      EXTERIOR WALLS = 13.00
     INTERIOR BASE SLAB      = 2.63      BASE SLAB      = 13.00
     INTERIOR WALLS          =   CL      INTERIOR WALLS =  9.00
```

1.E.--LOAD DATA

1.E.1.--STANDARD LOAD CASES
NO STANDARD LOAD CASES

1.E.2--SPECIAL LOAD CASES

SPECIAL LOAD CASE NO. 1

MEM NO	LOAD DIRECT	LOAD TYPE	LOAD (LB)(PLF)	DISTANCE (FT) START	END	WEIGHTED END
21	Y	UNIF	-415.00	-.54	9.92	
22	Y	UNIF	-415.00	0.00	9.75	
23	Y	UNIF	-415.00	0.00	9.75	
24	Y	UNIF	-415.00	0.00	10.46	
22	Y	CONC	-3180.00	8.49		
23	Y	CONC	-3180.00	4.83		
23	Y	CONC	-3180.00	8.49		
24	Y	CONC	-3180.00	4.83		
11	Y	TRIA	-795.00	-.54	10.71	L
11	Y	TRIA	-120.00	-.54	10.71	R
15	Y	TRIA	795.00	-.54	10.71	L
15	Y	TRIA	120.00	-.54	10.71	R
11	X	UNIF	-162.50	.54	9.54	
12	X	UNIF	-112.50	.54	9.54	
13	X	UNIF	-112.50	.54	9.54	
14	X	UNIF	-112.50	.54	9.54	
15	X	UNIF	-162.50	.54	9.54	
13	Y	TRIA	375.00	.54	6.54	L
3	Y	UNIF	-375.00	.38	9.38	
14	Y	TRIA	-375.00	.54	6.54	L

1.F.--REINFORCEMENT AREAS (SQIN) FOR INVESTIGATION

MEMBER	LEFT END		CENTERLINE		RIGHT END	
NO	TOP	BOTTOM	TOP	BOTTOM	TOP	BOTTOM
23	.60	.79	.60	.79	.60	.79
24	.60	.79	.60	.79	.60	.79
14	.44	.44	.44	.44	.44	.44
15	.44	.60	.44	.60	.44	.60
1	.31	.60	.31	.60	.31	.60
2	.31	.60	.31	.60	.31	.60
3	.31	.60	.31	.60	.31	.60
4	.31	.60	.31	.60	.31	.60

SCHEMATIC OF CULVERT:

```
*--21--*--22--*--23--*--24--*
!      !      !      !      !
!      !      !      !      !
11     12     13     14     15
!      !      !      !      !
!      !      !      !      !
*---1--*---2--*---3--*---4--*
```

LOCAL COORDINATE SYSTEMS:
    HORIZONTAL MEMBERS: ORIGIN AT LEFT END, X-AXIS TO RIGHT, Y-AXIS UP
    VERTICAL MEMBERS : ORIGIN AT BOTTOM, X-AXIS UP, Y-AXIS TO LEFT

SIGN CONVENTIONS:
    POSITIVE LATERAL LOAD ACTS IN PLUS Y DIRECTION
    POSITIVE BENDING MOMENT PRODUCES COMPRESSION
        ON PLUS Y FACE OF MEMBER
    POSITIVE SHEAR TENDS TO MOVE MEMBER IN PLUS Y DIRECTION
    POSITIVE AXIAL LOAD ACTS IN PLUS X DIRECTION
    POSITIVE AXIAL INTERNAL FORCE IS COMPRESSION
    POSITIVE CONCRETE STRESS IS COMPRESSION
    POSITIVE STRESS IN COMPRESSION REINFORCEMENT IS COMPRESSION
    POSITIVE STRESS IN TENSION REINFORCEMENT IS TENSION

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 15:34:00

2.A.--HEADING

INVESTIGATION OF FOUR CELL CULVERT
WITH WORKING STRESS DESIGN PROCEDURE
ONE SPECIAL LOAD CASE WITH
CONCENTRATED LOADS ON ROOF AND INTERNAL WATER

2.B.--SUMMARY OF RESULTS FOR SPECIAL LOAD CASE 1
INVESTIGATION USING WORKING STRESS DESIGN PROCEDURE

MEMBER 23		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-2.48	9.04	-4.83
AXIAL FORCE	(KIPS)	3.01	3.01	3.01
CONCRETE STRESS	(KSI)	.16	.58	.37
COMP. REINF. STRESS	(KSI)	.48	1.08	.58
TENS. REINF. STRESS	(KSI)	2.16	11.10	6.47
SHEAR FORCE AT D	(KIPS)	3.13		-2.99
SHEAR FS AT D (ACI63)		5.06		5.29
SHEAR FORCE AT 0.15LN	(KIPS)	2.96		-2.83
SHEAR FS AT 0.15LN (UI440)		3.19		3.34

MEMBER 24		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-3.70	5.68	-7.50
AXIAL FORCE	(KIPS)	2.59	2.59	2.59
CONCRETE STRESS	(KSI)	.25	.36	.53
COMP. REINF. STRESS	(KSI)	.48	.77	.58
TENS. REINF. STRESS	(KSI)	4.73	6.53	11.80
SHEAR FORCE AT D	(KIPS)	2.65		-3.46
SHEAR FS AT D (ACI63)		5.96		2.76
SHEAR FORCE AT 0.15LN	(KIPS)	2.49		-3.30
SHEAR FS AT 0.15LN (UI440)		3.78		2.93

MEMBER 14		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	-3.85	.27	2.20
AXIAL FORCE	(KIPS)	10.95	10.44	9.93
CONCRETE STRESS	(KSI)	.48	.11	.2[illegible]
COMP. REINF. STRESS	(KSI)	0.00	0.00	0.00
TENS. REINF. STRESS	(KSI)	3.87	-.57	.86
SHEAR FORCE AT D	(KIPS)	1.28		.42
SHEAR FS AT D (ACI63)		------		------
SHEAR FORCE AT 0.15LN	(KIPS)	NNNNNN		NNNNNN
SHEAR FS AT 0.15LN (UI440)		NNNNNN		NNNNNN

------ - SHEAR FS IS GREATER THAN TEN
NNNNNN - U-OF-I 440 SHEAR PROCEDURE DOES NOT APPLY FOR THIS MEMBER

MEMBER 15		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	1.47	.17	8.17
AXIAL FORCE	(KIPS)	5.78	5.04	4.31
CONCRETE STRESS	(KSI)	.09	.04	.67
COMP. REINF. STRESS	(KSI)	.50	.26	.86
TENS. REINF. STRESS	(KSI)	-.04	-.21	13.08
SHEAR FORCE AT D	(KIPS)	-1.11		2.22
SHEAR FS AT D (ACI63)		------		3.75
SHEAR FORCE AT 0.15LN	(KIPS)	-.80		2.10
SHEAR FS AT 0.15LN (UI440)		6.73		2.41

------ - SHEAR FS IS GREATER THAN TEN

MEMBER 1		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	2.64	-4.00	3.37
AXIAL FORCE	(KIPS)	3.25	3.25	3.25
CONCRETE STRESS	(KSI)	.20	.42	.27
COMP. REINF. STRESS	(KSI)	.49	.08	.50
TENS. REINF. STRESS	(KSI)	2.68	10.02	4.12
SHEAR FORCE AT D	(KIPS)	-2.37		2.65
SHEAR FS AT D (ACI63)		6.16		5.51
SHEAR FORCE AT 0.15LN	(KIPS)	-2.07		2.29
SHEAR FS AT 0.15LN (UI440)		2.13		1.93

MEMBER 2		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	.44	-3.33	10.55
AXIAL FORCE	(KIPS)	2.61	2.61	2.61
CONCRETE STRESS	(KSI)	.03	.35	.88
COMP. REINF. STRESS	(KSI)	.19	.04	.16
TENS. REINF. STRESS	(KSI)	-.05	8.49	19.33
SHEAR FORCE AT D	(KIPS)	-1.98		4.34
SHEAR FS AT D (ACI63)		4.18		1.98
SHEAR FORCE AT 0.15LN	(KIPS)	-1.59		3.90
SHEAR FS AT 0.15LN (UI440)		2.75		1.34

MEMBER 3		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	6.64	.71	8.46
AXIAL FORCE	(KIPS)	1.01	1.01	1.01
CONCRETE STRESS	(KSI)	.55	.05	.70
COMP. REINF. STRESS	(KSI)	-.03	.15	-.10
TENS. REINF. STRESS	(KSI)	12.73	.63	16.46
SHEAR FORCE AT D	(KIPS)	-2.19		2.71
SHEAR FS AT D (ACI63)		3.83		3.08
SHEAR FORCE AT 0.15LN	(KIPS)	-1.90		2.36
SHEAR FS AT 0.15LN (UI440)		2.72		2.18

MEMBER 4		LEFT END	CENTERLINE	RIGHT END
BENDING MOMENT	(K-FT)	11.89	-6.48	.05
AXIAL FORCE	(KIPS)	2.56	2.56	2.56
CONCRETE STRESS	(KSI)	.99	.72	.02
COMP. REINF. STRESS	(KSI)	.10	-.71	.13
TENS. REINF. STRESS	(KSI)	22.12	20.85	-.11
SHEAR FORCE AT D	(KIPS)	-5.72		3.21
SHEAR FS AT D (ACI63)		1.53		2.58
SHEAR FORCE AT 0.15LN	(KIPS)	-5.16		2.59
SHEAR FS AT 0.15LN (UI440)		1.01		1.69

PROGRAM CORTCUL - DESIGN/INVESTIGATION OF ORTHOGONAL CULVERTS
DATE: 08/22/80 TIME: 15:34:29

3.A.--HEADING

INVESTIGATION OF FOUR CELL CULVERT
WITH WORKING STRESS DESIGN PROCEDURE
ONE SPECIAL LOAD CASE WITH
CONCENTRATED LOADS ON ROOF AND INTERNAL WATER

3.B.--RESULTS FOR SPECIAL LOAD CASE 1
INVESTIGATION USING WORKING STRESS DESIGN PROCEDURE

RESULTS FOR MEMBER 23, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	-.42	-3.83	3.68	0.00	3.01
.38	-.42	-2.48	3.53	0.00	3.01
2.63	-.42	4.40	2.59	0.00	3.01
4.83	-.42	9.11	1.68	0.00	3.01
4.83	-.42	9.11	-1.50	0.00	3.01
4.88	-.42	9.04	-1.52	0.00	3.01
7.13	-.42	4.56	-2.46	0.00	3.01
8.49	-.42	.82	-3.02	0.00	3.01
8.49	-.42	.82	-6.20	0.00	3.01
9.38	-.42	-4.83	-6.57	0.00	3.01
9.75	-.42	-7.32	-6.73	0.00	3.01

RESULTS FOR MEMBER 24, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	-.42	-4.88	3.21	0.00	2.59
.38	-.42	-3.70	3.05	0.00	2.59
2.63	-.42	2.11	2.12	0.00	2.59
4.83	-.42	5.77	1.20	0.00	2.59
4.83	-.42	5.77	-1.98	0.00	2.59
4.88	-.42	5.68	-2.00	0.00	2.59
7.13	-.42	.14	-2.93	0.00	2.59
9.38	-.42	-7.50	-3.86	0.00	2.59
9.92	-.42	-9.65	-4.09	0.00	2.59

RESULTS FOR MEMBER 14, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	0.00	-4.68	1.55	0.00	10.95
.54	0.00	-3.85	1.55	0.00	10.95
.54	-.38	-3.85	1.55	-.11	10.95
2.79	-.23	-1.20	.86	-.11	10.69
5.04	-.09	.27	.49	-.11	10.44
6.54	-.00	.93	.42	-.11	10.27
7.29	0.00	1.25	.42	-.11	10.19
9.54	0.00	2.20	.42	-.11	9.93
9.54	0.00	2.20	.42	0.00	9.93
10.13	0.00	2.45	.42	0.00	9.93

RESULTS FOR MEMBER 15, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	.76	2.52	-2.13	0.00	5.78
.54	.73	1.47	-1.73	0.00	5.78
.54	.73	1.47	-1.73	-.16	5.78
2.79	.60	-.69	-.24	-.16	5.41
5.04	.46	.17	.95	-.16	5.04
7.29	.33	3.35	1.83	-.16	4.68
9.54	.19	8.17	2.41	-.16	4.31
9.54	.19	8.17	2.41	0.00	4.31
10.13	.16	9.61	2.51	0.00	4.31

RESULTS FOR MEMBER 1, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	.60	4.31	-3.24	0.00	3.25
.54	.61	2.64	-2.91	0.00	3.25
2.79	.65	-2.33	-1.49	0.00	3.25
5.04	.69	-4.00	.02	0.00	3.25
7.29	.73	-2.17	1.62	0.00	3.25
9.54	.77	3.37	3.32	0.00	3.25
9.92	.78	4.66	3.61	0.00	3.25

RESULTS FOR MEMBER 2, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	.78	1.49	-2.97	0.00	2.61
.38	.79	.44	-2.67	0.00	2.61
2.63	.83	-3.55	-.85	0.00	2.61
4.88	.87	-3.33	1.06	0.00	2.61
7.13	.91	1.30	3.07	0.00	2.61
9.38	.95	10.55	5.17	0.00	2.61
9.75	.96	12.55	5.53	0.00	2.61

RESULTS FOR MEMBER 3, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	.96	7.73	-3.07	0.00	1.01
.38	.97	6.64	-2.71	0.00	1.01
.38	.59	6.64	-2.71	0.00	1.01
2.63	.63	2.07	-1.33	0.00	1.01
4.88	.68	.71	.14	0.00	1.01
7.13	.72	2.77	1.71	0.00	1.01
9.38	.76	8.46	3.37	0.00	1.01
9.38	1.13	8.46	3.37	0.00	1.01
9.75	1.14	9.80	3.79	0.00	1.01

RESULTS FOR MEMBER 4, LOAD CASE 1

DIST FROM LEFT END (FT)	LATERAL LOAD (KSF)	BENDING MOMENT (K-FT)	SHEAR (KIPS)	AXIAL LOAD (KSF)	AXIAL FORCE (KIPS)
0.00	1.14	14.49	-7.15	0.00	2.56
.38	1.15	11.89	-6.72	0.00	2.56
2.63	1.19	-.31	-4.10	0.00	2.56
4.88	1.23	-6.48	-1.38	0.00	2.56
7.13	1.27	-6.43	1.44	0.00	2.56
9.38	1.31	.05	4.34	0.00	2.56
9.92	1.32	2.60	5.06	0.00	2.56

APPENDIX C: VERIFICATION OF LOAD AND FORCE CALCULATIONS

Introduction

1. This appendix presents calculations to demonstrate procedures used by CORTCUL and to verify program results. Details and computer program results for the culvert-soil systems used for illustration are given in Appendix B.

2. The remainder of this appendix is organized as follows:

   a. The first section following this one illustrates conversion of soil and structure weights to applied loads.

   b. The next section compares member forces calculated by CORTCUL with those obtained by other methods.

   c. The next section verifies stresses and reinforcement areas produced by CORTCUL in the DESIGN mode for the WSD and SD procedures.

   d. The last section validates stresses and factors of safety generated by CORTCUL in the INVESTIGATION mode for the WSD and SD methods.

Verification of Standard Load Cases

System

3. The six-cell culvert and soil system shown schematically on sheet 1 of Figure C1 was designed by CORTCUL for two standard load cases (see pages B28-B42 of Appendix B).

Loads on roof

4. Uniform loads on the roof slabs are produced by moist soil, submerged soil, water, and slab dead weight. Only soil loads are altered by vertical pressure coefficients as indicated by the tabulation on sheet 2 of Figure C1.

Loads on vertical exterior walls

5. A trapezoidal variation of horizontal distributed load is produced on vertical exterior walls by moist soil, submerged soil, and water. Only soil loads are altered by horizontal pressure coefficients, as illustrated on sheet 2 of Figure C1. Load magnitudes at various elevations are compared on sheet 3 of Figure C1.

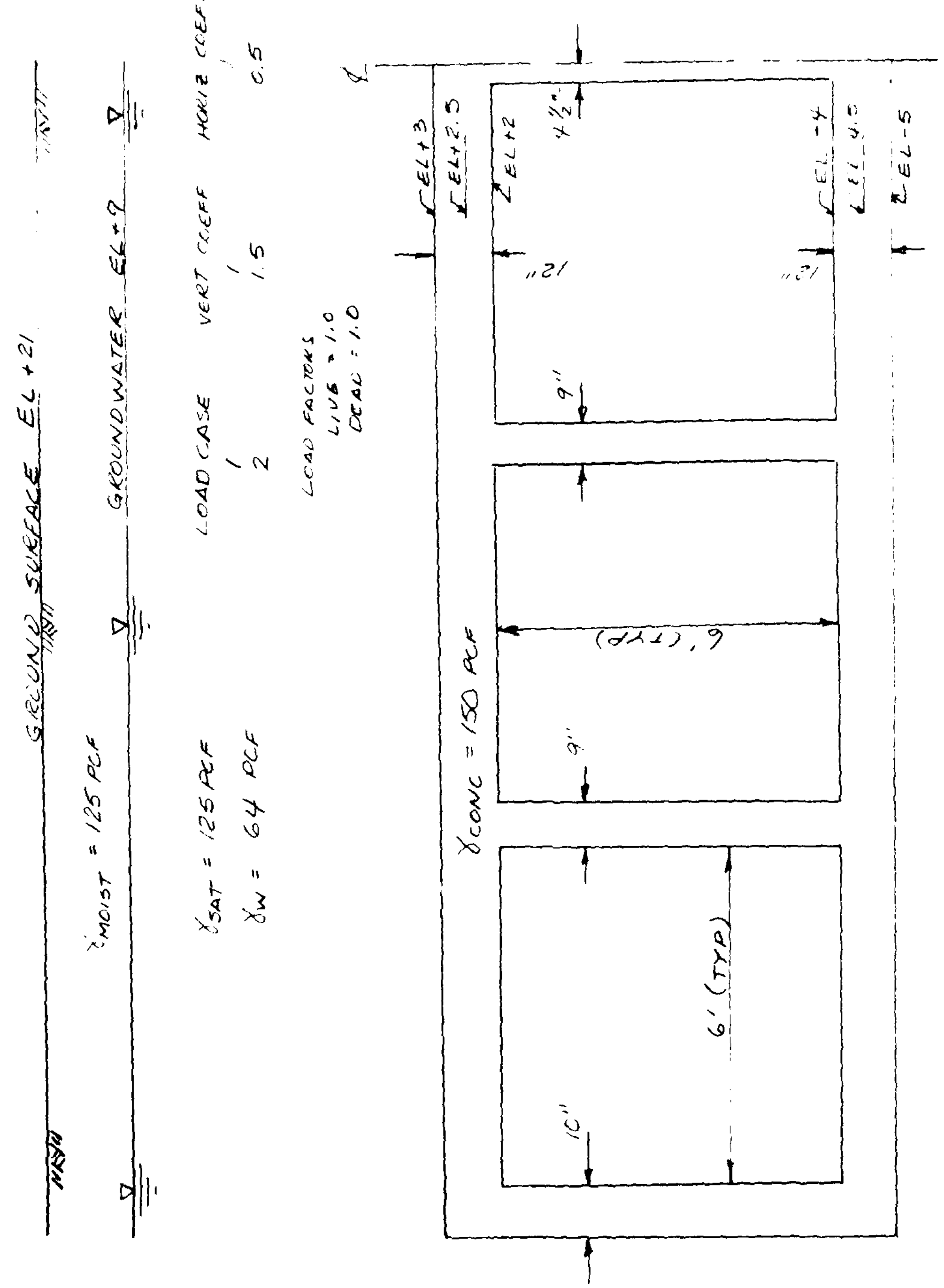


Figure C1. Verification of standard load cases (sheet 1 of 5)

LOADS ON ROOF (MEMBERS 21 THRU 26)

ITEM	FACTORS	LOAD (KSF) CASE 1	LOAD (KSF) CASE 2
MOIST SOIL	(21-9)125/1000	1.500	2.250
SUBMERGED SOIL	(9-3)(125-64)/1000	0.366	0.549
WATER	(9-3) 64/1000	0.384	0.384
SLAB WEIGHT	(1) 150/1000	0.150	0.150
TOTAL		2.400	3.333
COMPUTER PROGRAM		-2.40 (-↓)	-3.33

LOADS ON EXTERIOR WALL (MEMBER 11)

AT EL +3

ITEM	FACTORS	LOAD (KSF) CASE 1	LOAD (KSF) CASE 2
MOIST SOIL	(21-9) 125/1000	1.500	0.750
SUBMERGED SOIL	(9-3)(125-64)/1000	0.366	0.183
WATER	(9-3) 64/1000	0.384	0.384
TOTAL		2.250	1.317

AT EL -5

ITEM	FACTORS	LOAD (KSF) CASE 1	LOAD (KSF) CASE 2
MOIST SOIL	(21-9) 125/1000	1.500	0.750
SUBMERGED SOIL	(9+5)(125-64)/1000	0.854	0.427
WATER	(9+5) 64/1000	0.896	0.896
TOTAL		3.250	2.073

Figure C1. (sheet 2 of 3)

COMPARISON OF HAND CALCULATION AND COMPUTER PROGRAM RESULTS FOR EXTERIOR WALL (MEMBER 11)

EL	LOAD CASE 1 ≠ HAND*	LOAD CASE 1 ≠ PROG	LOAD CASE 2 HAND*	LOAD CASE 2 PROG ≠
+2.5	2.3125	-2.31	1.3643	-1.36
+2	2.3750	-2.38	1.4115	-1.41
-1 (¢)	2.7500	-2.75	1.6950	-1.70
-4	3.1250	-3.13	1.9785	-1.98
-4.5	3.1875	-3.19	2.0258	-2.03

* BY LINEAR INTERPOLATION BETWEEN LOADS AT EL +3 AND EL -5, SHEET 2 OF 3

≠ - INDICATES →

LOADS ON BASE (MEMBERS 1 THRU 6)

ITEM	FACTORS	LOAD (KSF) CASE 1	LOAD (KSF) CASE 2
TOTAL LOAD ON ROOF (SHEET 1)		2.400	3.333
VERT. EXT. WALLS	2(10/12)(6)(150)/(41.42)/1000	0.036	0.036
VERT INT. WALLS	5(9/12)(6)(150)/(41.42)/1000	0.082	0.082
TOTAL		2.518	3.451
COMPUTER PROGRAM		2.52	3.45

Figure C1. (sheet 3 of 3)

Loads on base

6. The input data to the computer program (see page B33) specify a uniform distribution of base pressure. The program generates a uniform base pressure necessary to equilibrate the total load on the roof plus the weight of the vertical walls, as illustrated on sheet 3 of Figure C1.

Verification of Member Forces

System

7. The six-cell culvert designed by CORTCUL (pages B28-B42) and the final design forces for Load Case 2 (1.5 to 0.5) are used in this illustration. Final design dimensions and loads (converted to units of pounds and inches) are shown schematically on sheet 1 of Figure C2.

Methods of analysis

8. A plane frame structural model of a 1-ft slice of the culvert is used by CORTCUL for analysis. Joint locations and member identifications used in this comparison are shown on sheet 1 of Figure C2. Joints are defined at intersections of the center lines of vertical and horizontal walls and slabs. Additional joints are defined in the vicinity of wall-slab intersections to account for the effect of member sizes in these locations. Member segments near wall-slab intersections are treated like rigid lengths (see pages 33-39 of the main text). Additional rigid lengths are used at the exterior corners of the structure to account for loads applied beyond wall-slab center line intersections. Flexible members are assigned cross-sectional areas and moments of inertia consistent with the dimension of the 1-ft slice of the culvert.

9. Member forces obtained by CORTCUL are compared with the following methods:

a. CFRAME* with rigid lengths. Rigid lengths were assigned moduli of elasticity equal to 1000 times the parent material property. Program output is shown in Table C1.

b. CFRAME without rigid lengths. All members have the parent material modulus of elasticity. Program output is shown in Table C2.

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* CFRAME is documented in "User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)," Instruction Report O-79-2, March 1979, Waterways Experiment Station.

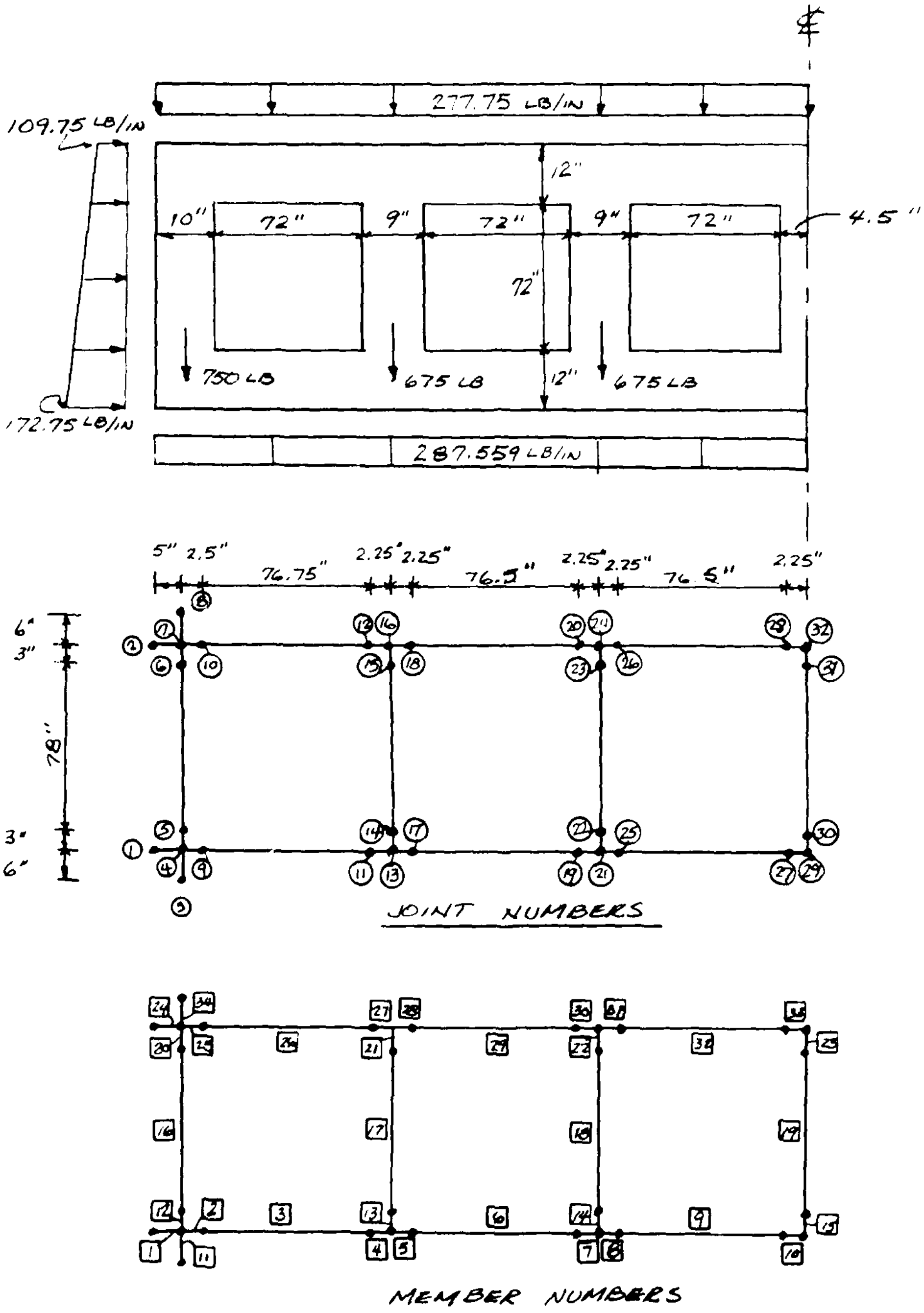

Figure C2. Verification of member force calculations (sheet 1 of 4)

JOINT MOMENTS (KIP-FT)

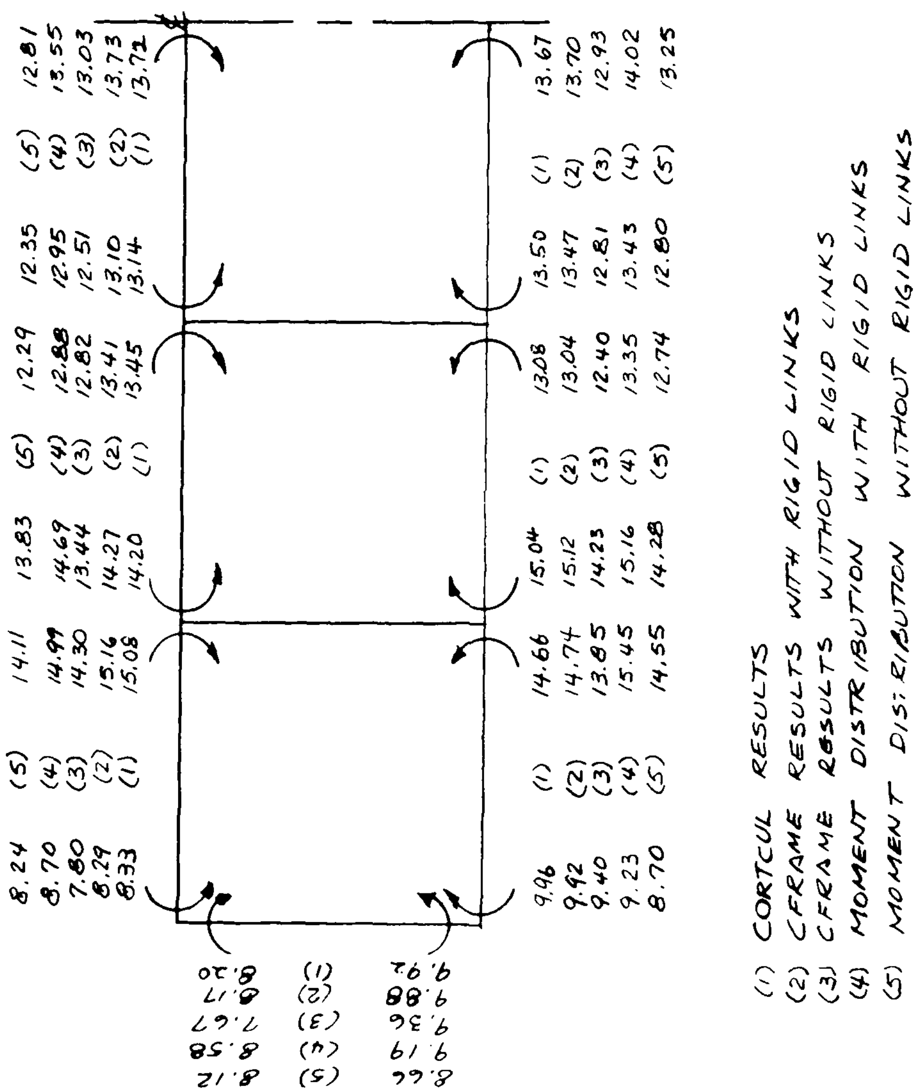

Figure C2. (sheet 2 of 4)

JOINT SHEARS (KIPS)

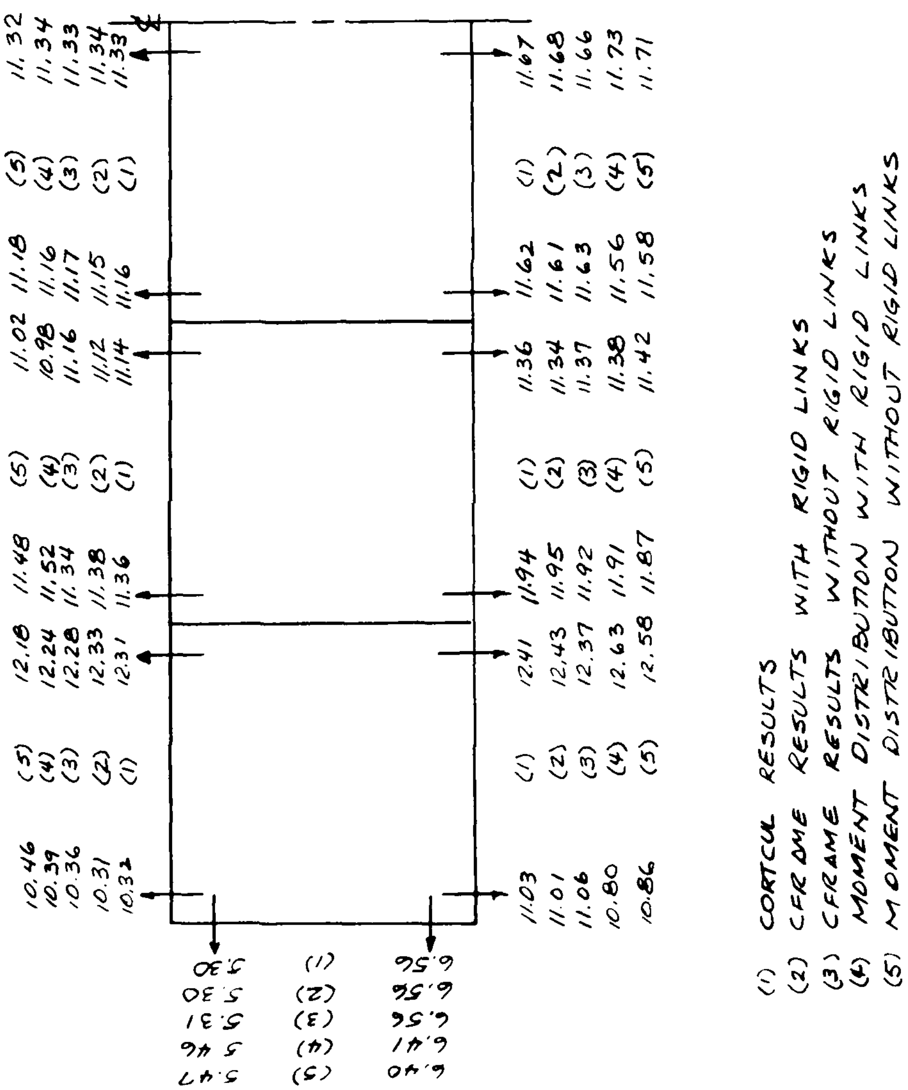

Figure C2. (sheet 3 of 4)

AXIAL FORCES (KIPS)

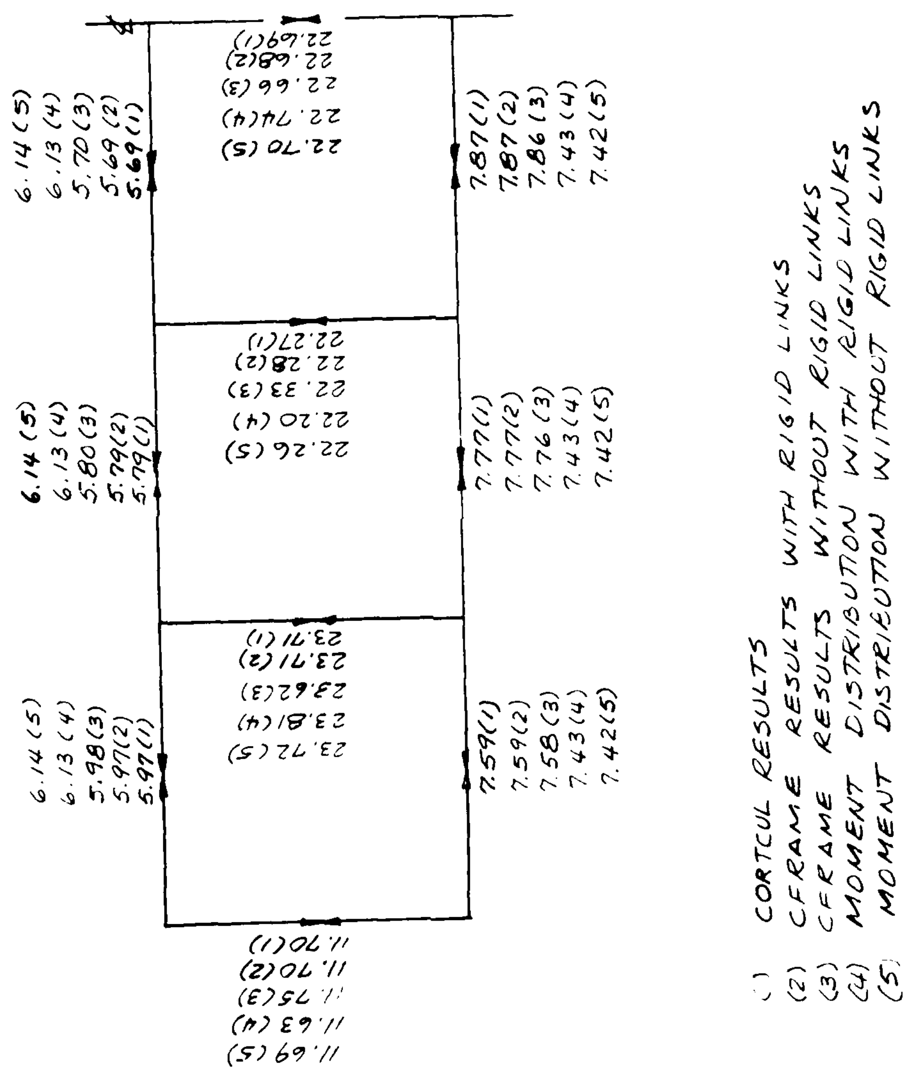

Figure C2. (sheet 4 of 4)

Table C1

Output from Program CFRAME for Six-Cell Culvert

With Rigid Links

```
* * * * * * * * * * * * * * * * * *
PROGRAM CFRAME V01.05 06JUL79
* * * * * * * * * * * * * * * * * *

RUN DATE      80/11/24.
RUN TIME  =   11.57.10.

CFRAME SOLUTION FOR SIX CELL CULVERT
DESIGNED BYCORTCUL, FOR 1.5 TO 0.5 LOADING
FRAME SOLUTION WITH RIGID LINKS
 *** JOINT DATA ***
```

			FIXITY					
JOINT	X	Y	X	Y	R	KX	KY	KR
1	-5.00	0.00						
2	-5.00	84.00						
3	0.00	-6.00						
4	0.00	0.00						
5	0.00	3.00						
6	0.00	81.00						
7	0.00	84.00						
8	0.00	90.00						
9	2.50	0.00						
10	2.50	84.00						
11	79.25	0.00						
12	79.25	84.00						
13	81.50	0.00						
14	81.50	3.00						
15	81.50	81.00						
16	81.50	84.00						
17	83.75	0.00						
18	83.75	84.00						
19	160.25	0.00						
20	160.25	84.00						
21	162.50	0.00						
22	162.50	3.00						
23	162.50	81.00						
24	162.50	84.00						
25	164.75	0.00						
26	164.75	84.00						
27	241.25	0.00						
28	241.25	84.00						
29	243.50	0.00	*	*	*			
30	243.50	3.00						
31	243.50	81.00						
32	243.50	84.00	*		*			

(Continued)

Table C1 (Continued)

*** MEMBER DATA ***

MEMBER	END A	END B	LENGTH	I	A	AS	E	G
1	1	4	5.00	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
2	4	9	2.50	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
3	9	11	76.75	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
4	11	13	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
5	13	17	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
6	17	19	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
7	19	21	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
8	21	25	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
9	25	27	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
10	27	29	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
11	3	4	6.00	.1000E+04	.1200E+03	0.	.3834E+10	.1598E+10
12	4	5	3.00	.1000E+04	.1200E+03	0.	.3834E+10	.1598E+10
13	13	14	3.00	.7290E+03	.1080E+03	0.	.3834E+10	.1598E+10
14	21	22	3.00	.7290E+03	.1080E+03	0.	.3834E+10	.1598E+10
15	29	30	3.00	.7290E+03	.5400E+02	0.	.3834E+10	.1598E+10
16	5	6	78.00	.1000E+04	.1200E+03	0.	.3834E+07	.1598E+07
17	14	15	78.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
18	22	23	78.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
19	30	31	78.00	.7290E+03	.5400E+02	0.	.3834E+07	.1598E+07
20	6	7	3.00	.1000E+04	.1200E+03	0.	.3834E+10	.1598E+10
21	15	16	3.00	.7290E+03	.1080E+03	0.	.3834E+10	.1598E+10
22	23	24	3.00	.7290E+03	.1080E+03	0.	.3834E+10	.1598E+10
23	31	32	3.00	.7290E+03	.5400E+02	0.	.3834E+10	.1598E+10
24	2	7	5.00	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
25	7	10	2.50	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
26	10	12	76.75	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
27	12	16	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
28	16	18	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
29	18	20	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
30	20	24	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
31	24	26	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
32	26	28	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
33	28	32	2.25	.1728E+04	.1440E+03	0.	.3834E+10	.1598E+10
34	7	8	6.00	.1000E+04	.1200E+03	0.	.3834E+10	.1598E+10

(Continued)

*** LOAD CASE 1 DATA ***

MEMBER	LA	PA	LB	PB	ANGLE
1	0.00	-.2876E+03	5.00	-.2876E+03	0.00
2	0.00	-.2876E+03	2.50	-.2876E+03	0.00
3	0.00	-.2876E+03	76.75	-.2876E+03	0.00
4	0.00	-.2876E+03	2.25	-.2876E+03	0.00
5	0.00	-.2876E+03	2.25	-.2876E+03	0.00
6	0.00	-.2876E+03	76.50	-.2876E+03	0.00
7	0.00	-.2876E+03	2.25	-.2876E+03	0.00
8	0.00	-.2876E+03	2.25	-.2876E+03	0.00
9	0.00	-.2876E+03	76.50	-.2876E+03	0.00
10	0.00	-.2876E+03	2.25	-.2876E+03	0.00
11	0.00	.1728E+03	6.00	.1688E+03	0.00
12	0.00	.1688E+03	3.00	.1668E+03	0.00
16	0.00	.1668E+03	78.00	.1157E+03	0.00
20	0.00	.1157E+03	3.00	.1137E+03	0.00
24	0.00	.2778E+03	5.00	.2778E+03	0.00
25	0.00	.2778E+03	2.50	.2778E+03	0.00
26	0.00	.2778E+03	76.75	.2778E+03	0.00
27	0.00	.2778E+03	2.25	.2778E+03	0.00
28	0.00	.2778E+03	2.25	.2778E+03	0.00
29	0.00	.2778E+03	76.50	.2778E+03	0.00
30	0.00	.2778E+03	2.25	.2778E+03	0.00
31	0.00	.2778E+03	2.25	.2778E+03	0.00
32	0.00	.2778E+03	76.50	.2778E+03	0.00
33	0.00	.2778E+03	2.25	.2778E+03	0.00
34	0.00	.1137E+03	6.00	.1098E+03	0.00

JOINT	FORCE X	FORCE Y	MOMENT
4	0.	-.7500E+03	0.
13	0.	-.6750E+03	0.
21	0.	-.6750E+03	0.
29	0.	-.3375E+03	0.

(Continued)

Table C1 (Continued)

LOAD CASE 1

MEMBER END FORCES

MEMBER	JOINT	AXIAL	SHEAR	MOMENT	MOMENT EXTREMA	LOCATION
1	1	0.	-.1236E-04	-.7172E-04	.3594E+04	5.00
	4	0.	-.1438E+04	.3594E+04	-.7172E-04	0.00
2	4	-.7588E+04	-.1101E+05	.1190E+06	.1190E+06	0.00
	9	-.7588E+04	.1029E+05	.9243E+05	.9243E+05	2.50
3	9	-.7588E+04	-.1029E+05	.9243E+05	.1497E+06	76.75
	11	-.7588E+04	-.1178E+05	.1497E+06	-.9161E+05	35.31
4	11	-.7588E+04	.1178E+05	.1497E+06	.1769E+06	2.25
	13	-.7588E+04	-.1243E+05	.1769E+06	.1497E+06	0.00
5	13	-.7768E+04	-.1195E+05	.1814E+06	.1814E+06	0.00
	17	-.7768E+04	.1131E+05	.1552E+06	.1552E+06	2.25
6	17	-.7768E+04	-.1131E+05	.1552E+06	.1552E+06	0.00
	19	-.7768E+04	-.1069E+05	.1317E+06	-.6702E+05	39.78
7	19	-.7768E+04	.1069E+05	.1317E+06	.1565E+06	2.25
	21	-.7768E+04	-.1134E+05	.1565E+06	.1317E+06	0.00
8	21	-.7872E+04	-.1161E+05	.1616E+06	.1616E+06	0.00
	25	-.7872E+04	.1096E+05	.1362E+06	.1362E+06	2.25
9	25	-.7872E+04	-.1096E+05	.1362E+06	.1389E+06	76.50
	27	-.7872E+04	-.1103E+05	.1389E+06	-.7282E+05	38.25
10	27	-.7872E+04	.1103E+05	.1389E+06	.1644E+06	2.25
	29	-.7872E+04	-.1168E+05	.1644E+06	.1389E+06	0.00
11	3	0.	0.	-.1590E-04	-.1590E-04	0.00
	4	0.	.1025E+04	-.3086E+04	-.3086E+04	6.00
12	4	-.1170E+05	.6563E+04	-.1185E+06	-.9961E+05	3.00
	5	-.1170E+05	.6060E+04	-.9961E+05	-.1185E+06	0.00
13	13	-.2371E+05	.1798E+03	-.4438E+04	-.3898E+04	3.00
	14	-.2371E+05	-.1798E+03	-.3898E+04	-.4438E+04	0.00
14	21	.2228E+05	.1044E+03	.5096E+04	.4782E+04	3.00
	22	-.2228E+05	-.1044E+03	-.4782E+04	-.5096E+04	0.00
15	29	.1134E+05	0.	0.	0.	0.00
	30	-.1134E+05	0.	0.	0.	0.00
16	5	-.1170E+05	.6060E+04	.9961E+05	.1633E+05	39.00
	6	-.1170E+05	.4958E+04	-.8258E+05	.9961E+05	0.00
17	14	.2371E+05	.1798E+03	-.3898E+04	.1012E+05	78.00
	15	.2371E+05	.1798E+03	.1012E+05	.3898E+04	0.00
18	22	.2228E+05	.1044E+03	-.4782E+04	.3362E+04	78.00
	23	.2228E+05	.1044E+03	.3362E+04	.4782E+04	0.00
19	30	.1134E+05	0.	0.	0.	0.00
	31	.1134E+05	0.	0.	0.	0.00
20	6	-.1170E+05	.4958E+04	-.8258E+05	-.8258E+05	0.00

(Continued)

Table C1 (Concluded)

	7	.1170E+05	.5302E+04	-.9798E+05	.9798E+05	[illegible]
21	15	.2371E+05	.1798E+03	.1012E+05	.1066E+05	[illegible]
	16	.2371E+05	-.1798E+03	.1066E+05	.1012E+05	[illegible]
22	23	-.2228E+05	.1044E+03	.3362E+04	.3675E+04	[illegible]
	24	-.2228E+05	-.1044E+03	.3675E+04	.3362E+04	[illegible]
23	31	.1134E+05	0.	0.	0.	[illegible]
	32	.1134E+05	0.	0.	0.	[illegible]
24	2	0.	.2098E-04	-.1081E-03	-.1081E-03	[illegible]
	7	0.	.1389E+04	-.3472E+04	.3472E+04	[illegible]
25	7	-.5972E+04	.1031E+05	-.9945E+05	.7455E+05	[illegible]
	10	.5972E+04	.9612E+04	.7455E+05	-.9945E+05	[illegible]
26	10	-.5972E+04	.9612E+04	.7455E+05	.9172E+05	[illegible]
	12	-.5972E+04	.1170E+05	-.1548E+06	-.1548E+06	[illegible]
27	12	-.5972E+04	-.1170E+05	-.1548E+06	-.1548E+06	0.00
	16	-.5972E+04	.1233E+05	-.1819E+06	-.1819E+06	[illegible]
28	16	-.5792E+04	.1138E+05	-.1712E+06	-.1463E+06	[illegible]
	18	-.5792E+04	-.1075E+05	-.1463E+06	-.1712E+06	0.00
29	18	-.5792E+04	.1075E+05	-.1463E+06	[illegible]	[illegible]
	20	-.5792E+04	.1050E+05	-.1366E+06	-.1463E+06	0.00
30	20	-.5792E+04	-.1050E+05	-.1366E+06	.1366E+06	0.00
	24	-.5792E+04	.1112E+05	-.1609E+06	.1609E+06	[illegible]
31	24	-.5688E+04	.1115E+05	-.1572E+06	-.1328E+06	[illegible]
	26	-.5688E+04	-.1053E+05	-.1328E+06	-.1572E+06	0.00
32	26	-.5688E+04	.1053E+05	.1328E+06	.6676E+05	[illegible]
	28	-.5688E+04	.1072E+05	.1400E+06	-.1400E+06	76.50
33	28	-.5688E+04	-.1072E+05	-.1400E+06	-.1400E+06	0.00
	32	-.5688E+04	.1134E+05	-.1648E+06	-.1648E+06	[illegible]
34	7	0.	.6703E+03	-.1999E+04	-.2606E-04	6.00
	8	0.	0.	-.2606E-04	-.1999E+04	0.00

STRUCTURE REACTIONS

JOINT	FORCE X	FORCE Y	MOMENT
29	-.7872E+04	-.3694E-01	.1644E+06
32	-.5688E+04	.1278E-03	-.1648E+06
TOTAL	-.1356E+05	-.3682E-01	

Table C2

Output from Program CFRAME for Six-Cell Culvert

Without Rigid Links

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* * * *-*-* *-*-*-*-*-*-*-*-*
PROGRAM CFRAME V01.05 06JUL79
*-*-*-*-* *-*-*-*-*-*-*-*-*-*

RUN DATE =  80/11/24.
RUN TIME =  12.03.26.

CFRAME SOLUTION FOR SIX CELL CULVERT
DESIGNED BYCORTCUL, FOR 1.5 TO 0.5 LOADING
FRAME SOLUTION WITHOUT RIGID LINKS
 *** JOINT DATA ***
```

			FIXITY					
JOINT	X	Y	X	Y	R	KX	KY	KR
1	-5.00	0.00						
2	-5.00	84.00						
3	0.00	-6.00						
4	0.00	0.00						
5	0.00	3.00						
6	0.00	81.00						
7	0.00	84.00						
8	0.00	90.00						
9	2.50	0.00						
10	2.50	84.00						
11	79.25	0.00						
12	79.25	84.00						
13	81.50	0.00						
14	81.50	3.00						
15	81.50	81.00						
16	81.50	84.00						
17	83.75	0.00						
18	83.75	84.00						
19	160.25	0.00						
20	160.25	84.00						
21	162.50	0.00						
22	162.50	3.00						
23	162.50	81.00						
24	162.50	84.00						
25	164.75	0.00						
26	164.75	84.00						
27	241.25	0.00						
28	241.25	84.00						
29	243.50	0.00	*	*	*			
30	243.50	3.00						
31	243.50	81.00						
32	243.50	84.00	*		*			

(Continued)

Table C2 (Continued)

*** MEMBER DATA ***

MEMBER	END A	END B	LENGTH	I	A	AS	E	G
1	1	4	5.00	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
2	4	9	2.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
3	9	11	76.75	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
4	11	13	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
5	13	17	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
6	17	19	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
7	19	21	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
8	21	25	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
9	25	27	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
10	27	29	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
11	3	4	6.00	.1000E+04	.1200E+03	0.	.3834E+07	.1598E+07
12	4	5	3.00	.1000E+04	.1200E+03	0.	.3834E+07	.1598E+07
13	13	14	3.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
14	21	22	3.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
15	29	30	3.00	.7290E+03	.5400E+02	0.	.3834E+07	.1598E+07
16	5	6	78.00	.1000E+04	.1200E+03	0.	.3834E+07	.1598E+07
17	14	15	78.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
18	22	23	78.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
19	30	31	78.00	.7290E+03	.5400E+02	0.	.3834E+07	.1598E+07
20	6	7	3.00	.1000E+04	.1200E+03	0.	.3834E+07	.1598E+07
21	15	16	3.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
22	23	24	3.00	.7290E+03	.1080E+03	0.	.3834E+07	.1598E+07
23	31	32	3.00	.7290E+03	.5400E+02	0.	.3834E+07	.1598E+07
24	2	7	5.00	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
25	7	10	2.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
26	10	12	76.75	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
27	12	16	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
28	16	18	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
29	18	20	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
30	20	24	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
31	24	26	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
32	26	28	76.50	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
33	28	32	2.25	.1728E+04	.1440E+03	0.	.3834E+07	.1598E+07
34	7	8	6.00	.1000E+04	.1200E+03	0.	.3834E+07	.1598E+07

(Continued)

Table C2 (Continued)

*** LOAD CASE 1 DATA ***

MEMBER	LA	FA	LB	FB	ANGLE
1	0.00	-.2876E+03	5.00	-.2876E+03	0.00
2	0.00	-.2876E+03	2.50	-.2876E+03	0.00
3	0.00	-.2876E+03	76.75	-.2876E+03	0.00
4	0.00	-.2876E+03	2.25	-.2876E+03	0.00
5	0.00	-.2876E+03	2.25	-.2876E+03	0.00
6	0.00	-.2876E+03	76.50	-.2876E+03	0.00
7	0.00	-.2876E+03	2.25	-.2876E+03	0.00
8	0.00	-.2876E+03	2.25	-.2876E+03	0.00
9	0.00	-.2876E+03	76.50	-.2876E+03	0.00
10	0.00	-.2876E+03	2.25	-.2876E+03	0.00
11	0.00	.1728E+03	6.00	.1688E+03	0.00
12	0.00	.1688E+03	3.00	.1668E+03	0.00
16	0.00	.1668E+03	78.00	.1157E+03	0.00
20	0.00	.1157E+03	3.00	.1137E+03	0.00
24	0.00	.2778E+03	5.00	.2778E+03	0.00
25	0.00	.2778E+03	2.50	.2778E+03	0.00
26	0.00	.2778E+03	76.75	.2778E+03	0.00
27	0.00	.2778E+03	2.25	.2778E+03	0.00
28	0.00	.2778E+03	2.25	.2778E+03	0.00
29	0.00	.2778E+03	76.50	.2778E+03	0.00
30	0.00	.2778E+03	2.25	.2778E+03	0.00
31	0.00	.2778E+03	2.25	.2778E+03	0.00
32	0.00	.2778E+03	76.50	.2778E+03	0.00
33	0.00	.2778E+03	2.25	.2778E+03	0.00
34	0.00	.1137E+03	6.00	.1098E+03	0.00

JOINT	FORCE X	FORCE Y	MOMENT
4	0.	-.7500E+03	0.
13	0.	-.6750E+03	0.
21	0.	-.6750E+03	0.
29	0.	-.3375E+03	0.

(Continued)

Table C2 (Continued)

LOAD CASE 1

MEMBER END FORCES

MEMBER	JOINT	AXIAL	SHEAR	MOMENT	MOMENT EXTREMA	LOCATION
1	1	0.	0.	0.	.3594E+04	5.00
	4	0.	-.1438E+04	.3594E+04	0.	0.00
2	4	-.7583E+04	-.1106E+05	.1128E+06	.1128E+06	0.00
	9	-.7583E+04	.1034E+05	.8601E+05	.8601E+05	2.50
3	9	.7583E+04	-.1034E+05	.8601E+05	.1391E+06	76.25
	11	-.7583E+04	-.1173E+05	.1391E+06	-.9995E+05	35.31
4	11	-.7583E+04	.1173E+05	.1391E+06	.1662E+06	2.25
	13	.7583E+04	-.1237E+05	.1662E+06	.1391E+06	0.00
5	13	-.7760E+04	-.1192E+05	.1708E+06	.1708E+06	0.00
	17	-.7760E+04	.1127E+05	.1448E+06	.1448E+06	2.25
6	17	.7760E+04	-.1127E+05	.1448E+06	.1448E+06	0.00
	19	.7760E+04	-.1073E+05	.1239E+06	-.7609E+05	39.38
7	19	-.7760E+04	.1073E+05	.1239E+06	.1488E+06	2.25
	21	.7760E+04	-.1137E+05	.1488E+06	.1239E+06	0.00
8	21	-.7863E+04	-.1163E+05	.1537E+06	.1537E+06	0.00
	25	-.7863E+04	.1098E+05	.1283E+06	.1283E+06	2.25
9	25	-.7863E+04	-.1098E+05	.1283E+06	.1296E+06	76.50
	27	.7863E+04	-.1102E+05	.1296E+06	-.8140E+05	38.25
10	27	.7863E+04	.1102E+05	.1296E+06	.1552E+06	2.25
	29	-.7863E+04	-.1166E+05	.1552E+06	.1296E+06	0.00
11	3	0.	0.	0.	0.	0.00
	4	0.	.1025E+04	-.3086E+04	-.3086E+04	6.00
12	4	.1175E+05	.6559E+04	-.1123E+06	.9334E+05	3.00
	5	.1175E+05	.6055E+04	.9334E+05	-.1123E+06	0.00
13	13	.2362E+05	.1767E+03	-.4623E+04	-.4092E+04	3.00
	14	.2362E+05	.1767E+03	-.4092E+04	-.4623E+04	0.00
14	21	.2233E+05	.1027E+03	.4896E+04	.4588E+04	3.00
	22	.2233E+05	.1027E+03	-.4588E+04	-.4896E+04	0.00
15	29	.1133E+05	0.	0.	0.	0.00
	30	.1133E+05	0.	0.	0.	0.00
16	5	.1175E+05	.6055E+04	-.9334E+05	.2242E+05	39.00
	6	.1175E+05	.4962E+04	.7666E+05	-.9334E+05	0.00
17	14	.2362E+05	.1767E+03	.4092E+04	.9692E+04	78.00
	15	-.2362E+05	.1767E+03	.9692E+04	.4092E+04	0.00
18	22	-.2233E+05	.1027E+03	-.4588E+04	.3426E+04	78.00
	23	.2233E+05	.1027E+03	.3426E+04	-.4588E+04	0.00
19	30	-.1133E+05	0.	0.	0.	0.00
	31	.1133E+05	0.	0.	0.	0.00
20	6	.1175E+05	.4962E+04	.7666E+05	.7666E+05	0.00

(Continued)

Table C2 (Concluded)

	7	-.1175E+05	.5306E+04	-.9207E+05	-.9207E+05	3.00
21	15	-.2362E+05	.1767E+03	.9692E+04	.1022E+05	3.00
	16	-.2362E+05	-.1767E+03	.1022E+05	.9692E+04	0.00
22	23	-.2233E+05	.1027E+03	.3426E+04	.3735E+04	3.00
	24	-.2233E+05	-.1027E+03	.3735E+04	.3426E+04	0.00
23	31	-.1133E+05	0.	0.	0.	0.00
	32	-.1133E+05	0.	0.	0.	0.00
24	2	0.	0.	0.	0.	0.00
	7	0.	.1389E+04	-.3472E+04	-.3472E+04	5.00
25	7	-.5977E+04	.1036E+05	-.9354E+05	-.6851E+05	2.50
	10	-.5977E+04	-.9667E+04	-.6851E+05	-.9354E+05	0.00
26	10	-.5977E+04	.9667E+04	-.6851E+05	.9968E+05	35.31
	12	-.5977E+04	.1165E+05	-.1446E+06	-.1446E+06	76.75
27	12	-.5977E+04	-.1165E+05	-.1446E+06	-.1446E+06	0.00
	16	-.5977E+04	.1228E+05	-.1716E+06	-.1716E+06	2.25
28	16	-.5800E+04	.1134E+05	-.1613E+06	-.1365E+06	2.25
	18	-.5800E+04	-.1072E+05	-.1365E+06	-.1613E+06	0.00
29	18	-.5800E+04	.1072E+05	-.1365E+06	.7022E+05	38.25
	20	-.5800E+04	.1053E+05	-.1294E+06	-.1365E+06	0.00
30	20	-.5800E+04	-.1053E+05	-.1294E+06	-.1294E+06	0.00
	24	-.5800E+04	.1116E+05	-.1538E+06	-.1538E+06	2.25
31	24	-.5697E+04	.1117E+05	-.1501E+06	-.1256E+06	2.25
	26	-.5697E+04	-.1055E+05	-.1256E+06	-.1501E+06	0.00
32	26	-.5697E+04	.1055E+05	-.1256E+06	.7457E+05	38.25
	28	-.5697E+04	.1070E+05	-.1316E+06	-.1316E+06	76.50
33	28	-.5697E+04	-.1070E+05	-.1316E+06	-.1316E+06	0.00
	32	-.5697E+04	.1133E+05	-.1564E+06	-.1564E+06	2.25
34	7	0.	.6703E+03	-.1999E+04	0.	6.00
	8	0.	0.	0.	-.1999E+04	0.00

STRUCTURE REACTIONS

JOINT	FORCE X	FORCE Y	MOMENT
29	-.7863E+04	-.3650E-01	.1552E+06
32	-.5697E+04	0.	-.1564E+06
TOTAL	-.1356E+05	-.3650E-01	

c. Moment distribution with rigid lengths.

d. Moment distribution without rigid lengths.

Discussion of results

10. Results obtained by the five procedures discussed above are tabulated on sheets 2-4 of Figure C2. The forces obtained by CORTCUL and CFRAME with rigid lengths are identical. Omission of the rigid length effect results in lower calculated bending moments but has only a slight effect on shears and axial forces.

11. The moment distribution procedure ignores the effect of axial shortening on bending moments. Due to axial shortening, the moment distribution procedure underestimates bending moments at some locations by approximately 7 percent in this illustration. The magnitude of the effect of axial shortening on bending moments depends on the relative axial and flexural shear stiffnesses of the culvert members. For some systems, particularly those with nonuniform base pressure distributions, bending moments predicted by moment distribution may be significantly in error.

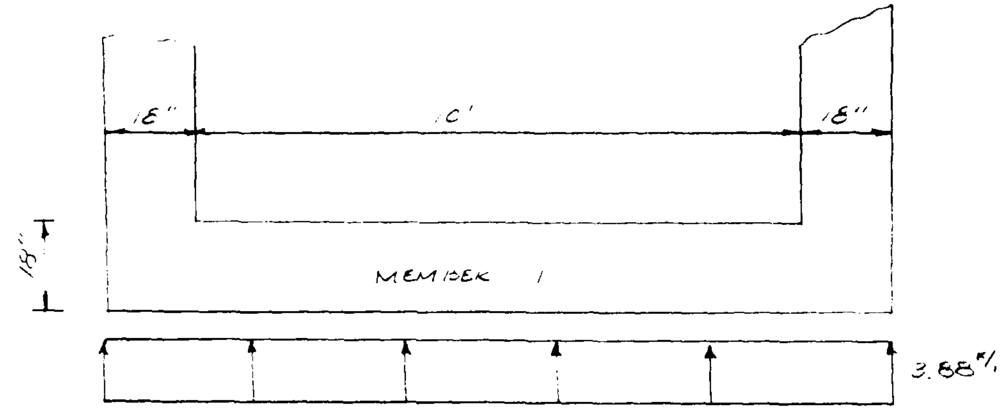
Verification of DESIGN Calculations

WSD procedures

12. The base member of the single-cell culvert designed by CORTCUL for one-to-one loading by WSD procedures and shear design option 2 (see pages B6-B11) is used for this illustration. Design dimensions, loading, material properties, and forces are shown on sheet 1 of Figure C3.

13. The clear span-to-depth ratio for this member dictates that University of Illinois 440 shear design (critical section at $0.15\ell_n$) be used. Shear and axial load at the critical section are shown on sheet 1 of Figure C3. Actual and allowable shear stresses at the critical location are shown on sheet 2 of Figure C3. Although the allowable shear stress is significantly greater than actual, reduction of the section thickness by 1 in. would place the section in the range of dimensions covered by ACI-63. The lower allowable shear stress permitted by ACI-63 would result in overstress at the critical section.

14. Compression stress in the concrete at the left end of the clear span is shown on sheets 2 and 3 of Figure C3. The actual compression stress is well below the allowable. Note that CORTCUL indicates that shear

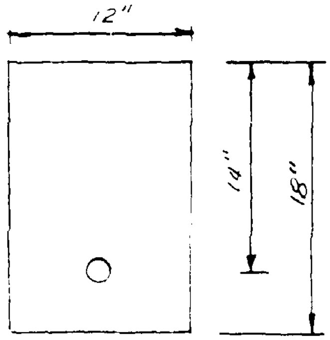


$f'_c = 4000$ PSI

$f_y = 40000$ PSI

$f_{ca} = 1800$ PSI

$f_{sa} = 20000$ PSI



$\ell_n = 120''$, $d = 14''$, $\ell_n/d = 8.57$ [illegible] $0.15\ell_n = 1.5'$

FORCES AT END OF CLEAR SPAN

$M = 32.07^{K FT}$, $P = 29.12^{K}$, $V = -19.42^{K}$

AT $0.15\ \ell_n$

$V = -19.42^{K} + 3.88(1.5) = -13.60^{K}$

$P = 29.12^{K}$

Figure C3. Verification of WSD DESIGN calculations (sheet 1 of 3)

CHECK SHEAR AT $0.15\, \ell_n$: U-OF-I 440 CONTROLS

$$v_c = V/bd = 13.60^{K}/(12'' \times 14'') = 80.9 \text{ PSI}$$

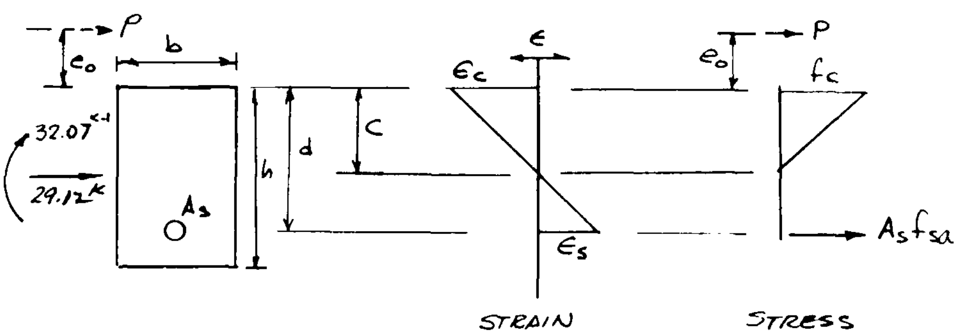
$$v_{ca} = \frac{1}{2}(11.5 - \ell_n/d)\sqrt{f'_c}\sqrt{1 + \frac{P}{5bh\sqrt{f'_c}}}$$

$$= \frac{1}{2}\left(11.5 - \frac{120}{14}\right)\sqrt{4000}\sqrt{1 + \frac{29.09\times10^3}{5(12)(18)\sqrt{4000}}}$$

$$v_{ca} = 110.6 \text{ PSI} > 80.9 \text{ PSI} \quad \text{OK}$$

CHECK DESIGN REINFORCEMENT AREA AT END OF CLEAR SPAN:

LOCATE NEUTRAL AXIS



$$\epsilon_c = \frac{c}{d-c}\,\epsilon_s \qquad f_c = \frac{c}{d-c}\,\frac{f_{sa}}{n}$$

$$\Sigma M_{REINF} = 0 \qquad f_c\, bc/2\,[d - c/3] - P[d + e_o] = 0$$

OR
$$c^3 - 3dc^2 - \frac{6Pn}{bf_{sa}}(d+e_o)c + \frac{6Pn}{bf_{sa}}(d+e_o)d = 0$$

Figure C3. (sheet 2 of 3)

VALUES:

$d = 14''$ $b = 12''$ $f_{sa} = 20$ KSI

$$e_o = \frac{M}{P} - h/2 = \frac{32.07(12)}{29.12} - \frac{18}{2} = 4.195''$$

$$E_c = 33\,w^{1.5}\sqrt{f'_c} = 33(150)^{1.5}\sqrt{4000} = 3.83\times10^6 \text{ PSI}$$

$$n = E_s/E_c = 29\times10^6 / 3.83\times10^6 = 7.56$$

CUBIC

$$C^3 - 42C^2 - 100.2C + 1402 = 0$$

$$C = 4.95''$$

CHECK CONCRETE STRESS

$$f_c = \frac{c}{d-c}\,\frac{f_{sa}}{n} = \frac{4.95}{14-4.95}\,\frac{(20)}{7.56} = 1.447 \text{ ksi} < 1.8$$

REQUIRED REINF. AREA

$$\Sigma F = 0: \quad A_s f_{sa} - f_c bc/2 - P = 0$$

$$A_s = [f_c bc/2 - P]/f_{sa}$$

$$A_s = [1.447(12)(4.95)/2 - 29.12]/20$$

$$A_s = 0.693 \text{ IN}^2 \quad (\text{PROGRAM } 0.69 \text{ IN}^2)$$

Figure C3. (sheet 3 of 3)

controls the design of this member.

15. Required reinforcement area at the left end of the clear span is verified on sheet 3 of Figure C3. The positive bending moment, compression in the top of the member, requires that the reinforcement be placed in the bottom of the section as indicated by CORTCUL output (see page B9).

ACI-63 SD procedures

16. The exterior vertical member of the six-cell culvert designed by CORTCUL by SD procedures and shear design option 1 (see pages B28-B42) is used in this illustration. Design dimensions, loading, forces, and design parameters produced by CORTCUL are shown on sheet 1 of Figure C4.

17. CORTCUL output indicates that shear controls the design of this member. The critical section for ACI-63 shear design is at a distance d above the lower face of the clear span. Shear, moment, and axial force at this location are given on sheet 1 of Figure C4. Allowable and actual shear stresses are compared on sheets 2 and 3 of Figure C4.

18. Required reinforcement area at the lower end of the clear span is verified on sheets 3 and 4 of Figure C4.

Verification of INVESTIGATION Calculations

WSD procedures

19. The roof slab over the third cell of the four-cell culvert investigated by CORTCUL by WSD procedures (see pages B56-B65) is used here for illustration. Dimensions and loads for this member are shown on sheet 1 of Figure C5.

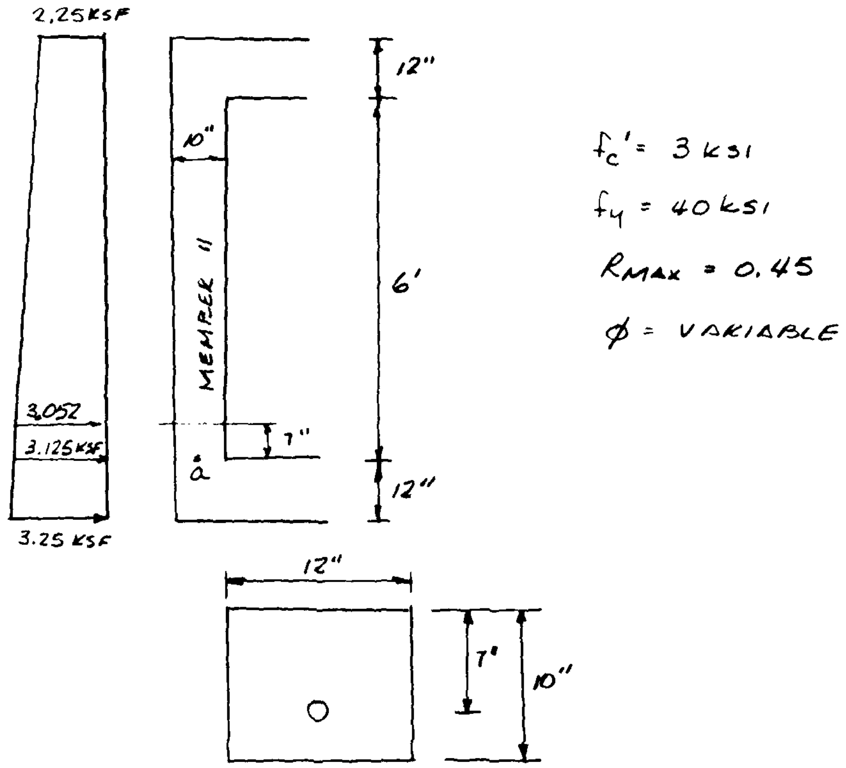
20. Shear factors of safety (at d for ACI-63 and at $0.15\ell_n$ for [illegible] 44) are compared on sheets 1 and 2 of Figure C5.

21. Material stresses at the left end of the clear span are compared on sheets 3 and 4 of Figure C5.

ACI-63 SD procedures

22. The roof slab over the left-hand cell of the three-cell culvert investigated by ACI-63 SD procedures (see pages B44-B54) for the 1.5-to-1.5 load case is used here for illustration. Loading and dimensions for this member are shown on sheet 1 of Figure C6.

23. Because the effective depth d exceeds $0.15\ell_n$, ACI-63 shear procedure is not used for this member. Shear factors of safety at $0.15\ell_n$



FORCES AT END OF CLEAR SPAN (POINT a, ABOVE)

$M = -7.73$ K-FT, $P = 10.01$ K, $V = 8.81$ K

FORCES AT d (= 7") ABOVE a:

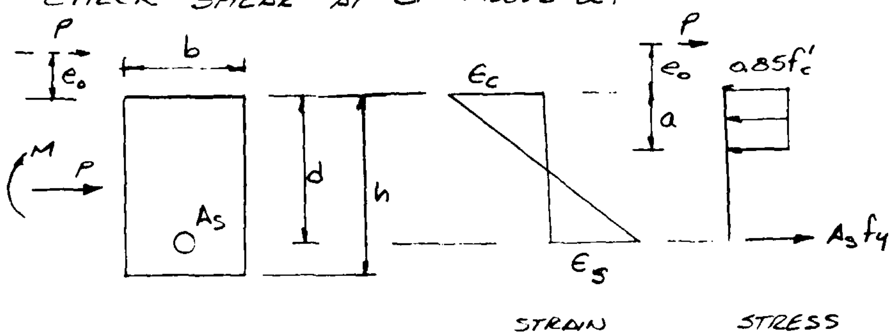
$$V = 8.81 - \frac{3.125 + 3.052}{2}\left(\frac{7}{12}\right) = 7.01^{K}$$

$$M = -7.73 + 8.81\left(\frac{7}{12}\right) - \frac{2(3.125) + 3.052}{6}\left(\frac{7}{12}\right)^2 = 3.12^{K'}$$

$$P = 10.01 - \frac{7}{12}\left(\frac{10}{12}\right)(0.15) = 9.94^{K}$$

Figure C4. Verification of SD DESIGN calculations (sheet 1 of 4)

CHECK SHEAR AT d ABOVE a:



$$v'_c = V/bd = \frac{7.01\times10^3}{12\times7} = 83.5 \text{ PSI}$$

$$v_{CA} = \phi\left[1.9\sqrt{f'_c} + 2500\,(A_s/bd)(Vd/M')\right]$$

$$M' = M - P(4h-d)/8 = 3.12(12) - 9.94(4\times10-7)/8$$

$$M' = -3.56 \text{ , SINCE } M' \text{ NEG } Vd/M' = 1$$

$$\phi = 0.85$$

DETERMINE A_s :

$$\Sigma M_{REINF} = 0: \quad 0.85f'_c\,ba\,[d - a/2] - \frac{P}{\phi}[d + e_o] = 0$$

$$\text{OR} \quad a^2 - 2da + \frac{2P}{0.85f'_c\,b\phi}[d + e_o] = 0$$

$$e_o = \frac{M}{P} - h/2 = \frac{3.12(12)}{9.94} - 5 = -1.233''$$

$$a^2 - 14a + 4.408 = 0$$

$$a = 0.323''$$

Figure C4. (sheet 2 of 4)

$\Sigma F = 0 \qquad A_s f_y - 0.85 f_c' b a + \frac{P}{\phi} = 0$

$$A_s = [0.85 f_c' b a - \frac{P}{\phi}] / f_y$$

$$A_s = [0.85 (3)(12)(0.323) - \frac{9.94}{0.85}] / 40 = -0.046$$

$$< 0, \therefore = 0$$

HENCE $\quad v_{ca} = \phi [1.9\sqrt{f_c'}] = 0.85 [1.9 \sqrt{3000}] = 88.5$ PSI

$v_{ca} > v_c$ OK

CALCULATE A_s AT FACE OF CLEAR SPAN (POINT a, SHEET 1)

$$\phi = 0.9 - \frac{2P}{f_c' b h} = 0.9 - \frac{2(10.01)}{3(12)(10)} = 0.844$$

$$e_o = \frac{M}{P} - \frac{h}{2} = \frac{7.73(12)}{10.02} - 5 = 4.26''$$

FROM EQN FOR a, SHEET 2

$$a^2 - 14a + 8.745 = 0$$

$$a = 0.655 \text{ IN}$$

$$A_s = [0.85(3)(12)(0.655) - \frac{10.01}{0.844}] / 40 = 0.204 \text{ IN}^2$$

(PROGRAM 0.20 IN²)

Figure C4. (sheet 3 of 4)

CHECK $A_S \le \rho_{MAX}\, A_{S\,BALANCE}$

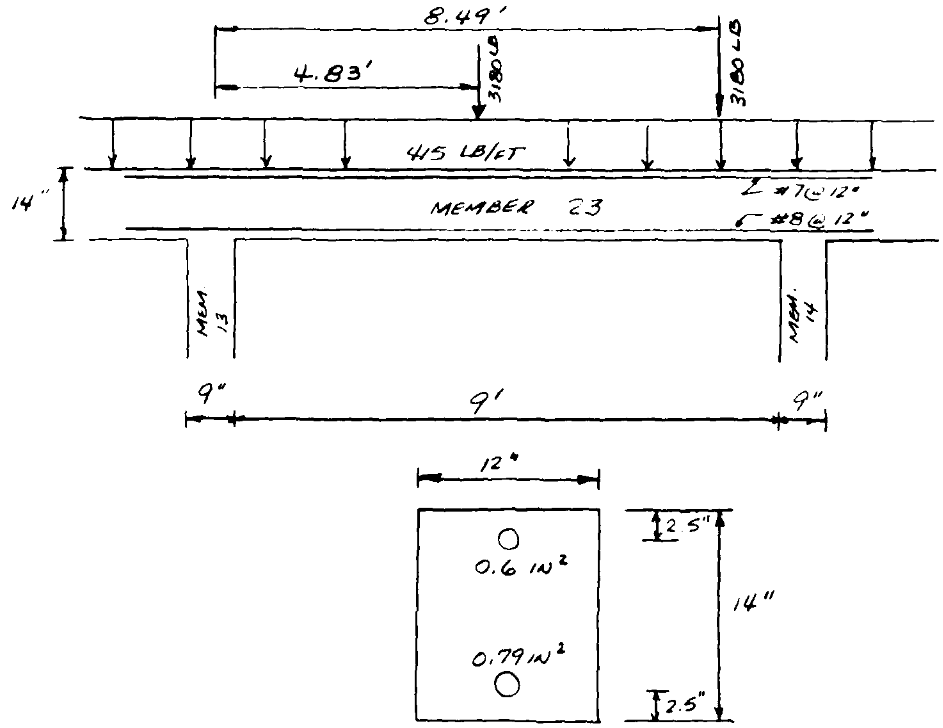
$$a_B = 0.85 \frac{\epsilon_c'}{\epsilon_c' + \epsilon_y} d = 0.85 \frac{0.003}{0.003 + \frac{40\times10^3}{29\times10^6}} (7)$$

$$a_B = 4.08 \text{ IN}$$

$$A_{SB} = \frac{0.85 f_c' b a_B}{f_y} = \frac{0.85(3)(12)(4.08)}{40} = 3.12 \text{ IN}^2$$

$$\rho_{MAX} A_{SB} = 0.45(3.12) = 1.40 \text{ IN}^2 > 0.2 \text{ IN}^2 \text{ OK}$$

Figure C4. (Sheet 4 of 4)



FORCES IN MEMBER 23

AT FACE OF MEMBER 13 $\quad M = -2.48$ k-FT

$P = 3.01$ K

$V = 3.53$ K

AT d FROM MEMBER 13: ($d = 11.5''$)

$$M = -2.48 + 3.53\left(\frac{11.5}{12}\right) - \frac{0.415}{2}\left(\frac{11.5}{12}\right)^2 = 0.71 \text{ k-FT}$$

$$V = 3.53 - 0.415\left(\frac{11.5}{12}\right) = 3.13^{k}$$

$$P = 3.02 \text{ k}$$

AT $0.15\,l_n$ FROM MEMBER 13 ($0.15\,l_n$) = 1.35'

$$M = -2.48 + 3.53(1.35) - \frac{0.415}{2}(1.35)^2 = 1.91 \text{ k-FT}$$

$$V = 3.53 - 1.35(0.415) = 2.97 \text{ K}$$

$$P = 3.01 \text{ k.}$$

Figure C5. Verification of WSD INVESTIGATION calculations (Sheet 1 of 4)

CHECK SHEAR FACTOR OF SAFETY AT d BY ACI 63

$$M' = M - P(4h - d)/8 = 0.68(12) - 3.02(4 \cdot 14 - 11.5)/8$$

$$M' = -8.6$$

$$\therefore \quad v_{ca} = 1.75\sqrt{f'_c}\,\sqrt{1 + 0.004\,P/(bh)}$$

$$= 1.75\sqrt{4000}\,\sqrt{1 + \frac{0.004(3.02)(1000)}{12(14)}}$$

$$v_{ca} = 114.6 \text{ PSI}$$

$$v_c = \frac{V}{bd} = \frac{3.13(1000)}{12(11.5)} = 22.6 \text{ PSI}$$

$$SF = \frac{v_{ca}}{v_c} = \frac{114.6}{22.6} = 5.07 \quad (\text{PROGRAM } SF = 5.06)$$

CHECK SHEAR FACTOR OF SAFETY AT $0.15 l_n$ BY U-OF-I 440

$$v_{ca} = \frac{1}{2}\left[(11.5 - l_n/d)\sqrt{f'_c}\,\sqrt{1 + \frac{P}{5bh\sqrt{f'_c}}}\right]$$

$$v_{ca} = \frac{1}{2}\left[\left(11.5 - \frac{9(12)}{11.5}\right)\sqrt{4000}\,\sqrt{1 + \frac{3.02(1000)}{5(12)(14)\sqrt{4000}}}\right]$$

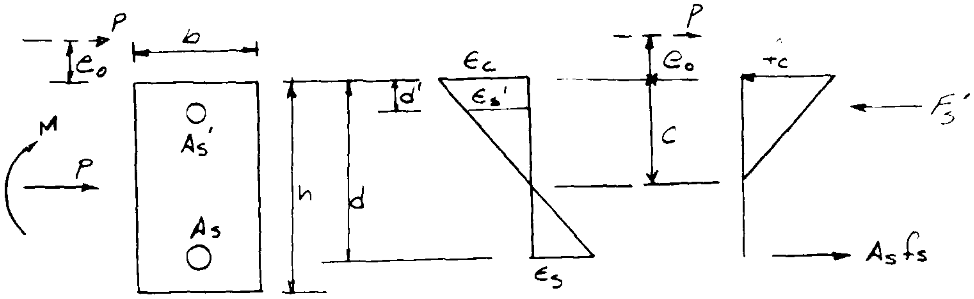
$$v_{ca} = 68.6 \text{ PSI}$$

$$v'_c = \frac{V}{bd} = \frac{2.97(1000)}{12(11.5)} = 21.5 \text{ PSI}$$

$$SF = \frac{v_{ca}}{v_c} = \frac{68.6}{21.5} = 3.19 \quad (\text{PROGRAM } SF = 3.19)$$

Figure C5. (sheet 2 of 4)

CHECK MATERIAL STRESSES AT LEFT END OF MEMBER 23



$$\epsilon_s' = \frac{c-d'}{c}\epsilon_c \qquad f_s' = \frac{c-d'}{c} n f_c$$

$$\epsilon_s = \frac{d-c}{c}\epsilon_c \qquad f_s = \frac{d-c}{c} n f_c$$

$$F_s' = A_s' \frac{c-d'}{c}(n-1) f_c$$

$$\Sigma M_{P@e_o} = 0$$

$$\frac{f_c bc}{2}\left[e_o + \frac{c}{3}\right] + A_s' \frac{c-d'}{c}(n-1) f_c \left[d' + e_o\right] - A_s \frac{d-c}{c} n f_c \left[d + e_o\right] = 0$$

OR
$$c^3 + 3e_o c^2 + \frac{6}{b}\left[A_s'(n-1)(d'+e_o) + A_s n (d+e_o)\right]c$$

$$- \frac{6}{b}\left[A_s'(n-1)(d'+e_o)d' + A_s n (d+e_o)d\right] = 0$$

$$e_o = \frac{M}{P} - \frac{h}{2} = \frac{2.48(12)}{3.01} - \frac{14}{2} = 2.89''$$

$A_s' = 0.79\ \text{IN}^2$, $A_s = 0.6\ \text{IN}^2$ $n = 7.563$

$d' = 2.5''$, $d = 11.5\ \text{in}$

THEN $c^3 + 8.80 c^2 + 46.8 c - 412 = 0$

OR $c = 4.12''$

Figure C5. (sheet 3 of 4)

$\Sigma F = 0$

$$\frac{f_c bc}{2} + A_s' \frac{c-d'}{c}(n-1) f_c - A_s \frac{d-c}{c} n f_c - P = 0$$

$$f_c = P \Big/ \left[\frac{bc}{2} + A_s' \frac{c-d'}{c}(n-1) - A_s \frac{d-c}{c} n \right]$$

$$f_c = 3.01 \Big/ \left[\frac{12(4.12)}{2} + 0.79 \frac{4.12-2.5}{4.12}(7.563-1) - 0.6 \frac{11.5-4.12}{4.12}(7.563) \right]$$

$f_c = 0.162$ KSI (PROGRAM $f_c = 0.16$ KSI)

$$f_s' = \frac{c-d'}{c} n f_c = \frac{4.12-2.5}{4.12}(7.563)(0.162)$$

$f_s' = 0.482$ KSI (PROGRAM $f_s' = 0.48$ KSI)

$$f_s = \frac{d-c}{c} n f_c = \frac{11.5-4.12}{4.12}(7.563)(0.162)$$

$f_s = 2.20$ KSI (PROGRAM $f_s = 2.16$ KSI)

Figure C5. (sheet 4 of 4)

AD-A100 968 DAWKINS (WILLIAM P) STILLWATER OK F/G 13/13
USER'S GUIDE: COMPUTER PROGRAM FOR DESIGN OR INVESTIGATION OF O--ETC(U)
MAR 81 W P DAWKINS DACW39-80-M-0334
UNCLASSIFIED WES-INSTRUCTION-K-81-7 NL

3 of 3
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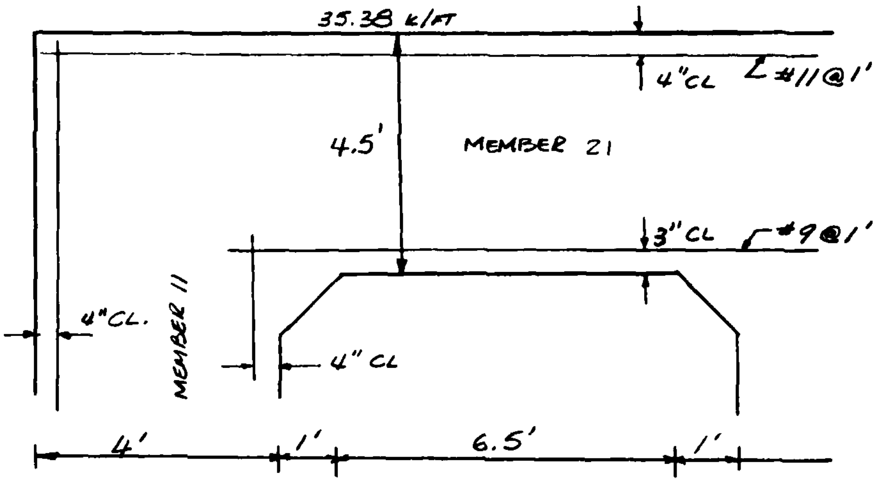
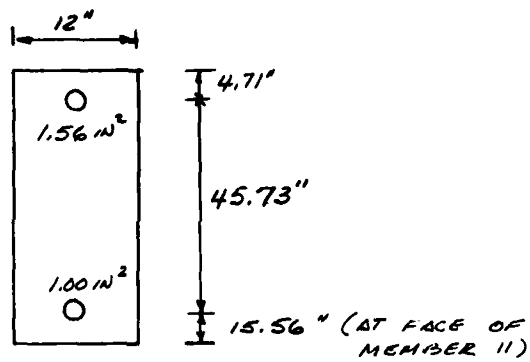


f'_c = 4 KSI

f_y = 40 KSI

ϕ = VARIABLE



FORCES IN MEMBER 21:

AT FACE OF MEMBER 11: $M = -209.14$ KFT
$P = 209.54^{K}$
FOR (-) M $d = 61.29"$
$h = 66"$

AT $0.15\,\ell_n$ (= 0.975') : $V = 99.01^{K}$
$P = 209.54^{K}$
$M = -95.8^{K'}$
FOR (-) M $d = 54" - 4.71" = 49.29"$
$h = 54"$

Figure C6. Verification of SD INVESTIGATION calculations (sheet 1 of 3)

CHECK SHEAR FACTOR OF SAFETY AT $0.15\, l_n$ BY U-OF-I 440

$$v_{ca} = \left[11.5 - \frac{l_n}{d}\right] \sqrt{f_c'} \sqrt{1 + \frac{P}{5bh\sqrt{f_c'}}}$$

$$= \left[11.5 - \frac{6.5(12)}{49.29}\right] \sqrt{4000} \sqrt{1 + \frac{209.54(1000)}{5(12)(54)\sqrt{4000}}}$$

$$v_{ca} = 892 \text{ PSI}$$

$$v_c = \frac{V}{bd} = \frac{99.01(1000)}{12(49.29)} = 167.4 \text{ PSI}$$

$$SF = \frac{v_{ca}}{v_c} = \frac{892}{167.4} = 5.33 \quad (\text{PROGRAM } SF = 5.33)$$

CHECK FLEXURE FACTOR OF SAFETY AT FACE OF MEMBER 11.

ACTUAL ECCENTRICITY $e = \frac{M}{P} = \frac{209.14(12)}{209.54} = 11.98''$

FOR P_N, M_N (ON INTERACTION CURVE) MUST USE TRIAL AND ERROR PROCESS AS FOLLOWS

1. ASSUME LOCATION OF NEUTRAL AXIS $- c$
2. DEPTH OF COMPRESSION BLOCK $- a = 0.85c$
3. CONCRETE FORCE $- P_c = 0.85 f_c' b a_\beta$
4. COMPRESSION REINF. STRAIN, STRESS, FORCE

$$\epsilon_s' = \frac{c - d'}{c}(0.003)$$

$$f_s' = E_s \epsilon_s' \leq 40 \text{ KSI}$$

$$F_s' = A_s' f_s'$$

Figure C6. (sheet 2 of 3)

5. TENSION REINF. FORCE - $F_S = A_S f_y$

6. NOMINAL AXIAL FORCE

$$P_N = F_C + F_S' - F_S$$

7. NOMINAL MOMENT

$$M_N = F_C\left[\frac{h}{2} - \frac{a}{2}\right] + F_S'\left[\frac{h}{2} - d'\right] + F_S\left[d - \frac{h}{2}\right]$$

8. ECCENTRICITY $e = \frac{M_N}{P_N}$

9. ADJUST C UNTIL $\frac{M_N}{P_N}$ = ACTUAL ECCENTRICITY

C''	a''	$F_C^{\,k}$	ϵ_s'	f_s' ksi	F_s' K	F_s K	P_N K	M_N K"	e "
53	45.05	1838	0.0021	40	40	62.4	1816	21720	11.96

CALCULATE ϕ:

$$\phi_1 = 0.9/[1 + 2P_N/(f_c' bh)] = \frac{0.9}{1 + \frac{2(1816)}{4(12)(66)}} = \cancel{0.42} \quad 0.7$$

$$\phi_2 = 0.9 - 0.2P_N/P_B = 0.9 - 0.2(1816)/1434 = \cancel{0.65} \quad 0.7$$

FOR P_B: $a_B = 0.85 \frac{0.003}{0.003 + \frac{40\times10^3}{29\times10^6}}(61.29) = 35.7''$

$C_B = 42.0''$

$\epsilon_s' = 0.0019$, $f_s' = 40$ ksi

$P_B = 0.85 f_c' a_B b + A_s' f_s' - A_s f_y = 1434$ KIPS

$SF = \phi P_N/P = 0.7(1816)/209.54 = 6.07$ (PROGRAM 5.98)

Figure C6. (sheet 3 of 3)

from the U-of-I 440 procedure are compared on sheet 2 of Figure C6.

24. Hand calculations for the flexure factor of safety at the left face of the clear span are outlined on sheets 2 and 3 of Figure C6. Note that the increase in effective depth d due to the haunch is included. The difference in flexure factors of safety is due to truncation in the hand calculations.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

WATERWAYS EXPERIMENT STATION REPORTS PUBLISHED UNDER THE COMPUTER-AIDED STRUCTURAL ENGINEERING (CASE) PROJECT

	Title	Date
Technical Report K-78-1	List of Computer Programs for Computer-Aided Structural Engineering	Feb 1978
Instruction Report O-79-2	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Mar 1979
Technical Report K-80-1	Survey of Bridge-Oriented Design Software	Jan 1980
Technical Report K-80-2	Evaluation of Computer Programs for the Design/Analysis of Highway and Railway Bridges	Jan 1980
Instruction Report K-80-1	User's Guide: Computer Program for Design/Review of Curvilinear Conduits/Culverts (CURCON)	Feb 1980
Instruction Report K-80-3	A Three-Dimensional Finite Element Data Edit Program	Mar 1980
Instruction Report K-80-4	A Three-Dimensional Stability Analysis/Design Program (3DSAD)	
	Report 1: General Geometry Module	Jun 1980
Instruction Report K-80-6	Basic User's Guide: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Technical Report K-80-4	Documentation of Finite Element Analyses	
	Report 1: Longview Outlet Works Conduit	Dec 1980
	Report 2: Anchored Wall Monolith, Bay Springs Lock	Dec 1980
Technical Report K-80-5	Basic Pile Group Behavior	Dec 1980
Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods (CSHTWAL)	
	Report 1: Computational Processes	Feb 1981
	Report 2: Interactive Graphics Options	Mar 1981
Instruction Report K-81-3	Validation Report: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Feb 1981
Instruction Report K-81-4	User's Guide: Computer Program for Design and Analysis of Cast-in-Place Tunnel Linings (NEWTUN)	Mar 1981
Instruction Report K-81-6	User's Guide: Computer Program for Optimum Nonlinear Dynamic Design of Reinforced Concrete Slabs Under Blast Loading (CBARCS)	Mar 1981
Instruction Report K-81-7	User's Guide: Computer Program for Design or Investigation of Orthogonal Culverts (CORTCUL)	Mar 1981

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